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AUTHOR Besancon, Francis E.
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ABSTRACT

A curriculum was developed to provide the electromechanical skills necessary to operate and repair industrial robots to students at the secondary and adult vocational levels. To determine requirements for entry-level positions in the robotics industry, manufacturers and employers of industrial robots were contacted. No particular entry-level skills were expected for jobs involving the operation and routine maintenance of robots. Positions entailing robot repair and troubleshooting generally required the skills of an electronics technician. Following the nine-page final report is the robotics curriculum. Materials are provided for four courses: electronics I (AC and DC fundamentals), electronics II (control devices and circuit theory), digital electronics, and robotics. Components presented for each course include an introduction, course objectives, and an outline of course content (objectives, content, laboratory experiments and demonstrations) for each of the 7 to 18 units within the course. Some recommendations for student evaluation are made. Appendixes include results of a survey of employment practices in the robotics industry, sample job descriptions and requirements for employment in the robotics industry, and listings of manufacturers of industrial robots, recommended equipment, and textbooks and reference materials. (YLB)

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A SECONDARY-LEVEL CURRICULUM IN INDUSTRIAL ELECTRONICS AND ROBOTICS

FINAL REPORT

PREPARED BY
PLYMOUTH BOARD OF EDUCATION
TERRYVILLE, CONNECTICUT 06786

PREPARED FOR

CONNECTI[illegible] STATE DEPARTMENT OF EDUCATION
DIVISION OF VOCATIONAL AND ADULT EDUCATION
BUREAU OF VOCATIONAL PROGRAM PLANNING AND DEVELOPMENT
HARTFORD, CONNECTICUT 06115

Francis E. Besancon
Project Director

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JULY 15, 1984

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ABSTRACT

A SECONDARY-LEVEL CURRICULUM IN INDUSTRIAL ELECTRONICS AND ROBOTICS

Francis E. Besancon, Project Director
Plymouth Board of Education

The major objective of this project was to develop a curriculum to provide the electro-mechanical skills necessary to operate and repair industrial robots to students at the secondary school and adult vocational levels. The minimum theoretical and applied background required for sucessful participation in the training program was also established.

A search was conducted for existing curriculums which could be adapted for this project. None was found suitable for secondary-level or adult re-training programs.

To determine requirements for entry-level positions in the robotics industry, firms producing industrial robots were contacted. The Connecticut Department of Labor was also consulted for employment projections. No particular entry-level skills are expected for jobs involving the operation and routine maintenance of robots. Positions entailing robot repair and troubleshooting generally require the skills of an electronics technician.

This curriculum attempts to satisfy the requirements of employers in industries which manufacture or use industrial robots as well as the objectives of the Connecticut State Board of Education Division of Vocational Education. It reflects the need for flexible, transferable skills development, but also familiarizes students with the operation and general maintenance of industrial robots. This part of the curriculum can be implemented alone or as the culmination of an thorough-going electromechanical program. Thus, the curriculum can be used to provide entry-level skills for the robotics and industrial electronics fields. The curriculum is designed so that it may be used 1) to enrich currently operating technology curriculums; 2) as an independent curriculum offering; or 3) as a re-training program for adults.

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INTRODUCTION

STATEMENT OF THE PROBLEM AND OBJECTIVES

The problem addressed by this curriculum is the need for secondary-level training in robotics operation and repair to meet the employment requirements of industries that are becoming increasingly technologically sophisticated. In addressing this problem, the following objectives were established:

1. The first objective of this project was to develop a curriculum capable of providing students at the secondary school and adult vocational levels with the electro-mechanical skills necessary to operate and repair industrial robots. The curriculum includes:

    A. The overall objectives and criteria for student evaluation.

    B. Outlines for each course, including behavioral objectives for each section.

    C. Laboratory or shop problems, experiments and demonstrations designed to illustrate current electro-mechanical procedures and practices used in industry.

    D. Suggested equipment and supplies for implementing the curriculum.

    E. Sources for equipment and supplies.

    F. A comprehensive list of relevant text and reference materials and equipment suppliers.

    G. Information about firms which produce and/or employ industrial robots, emphasizing firms located in the Northeast.

2. The second objective was to establish guidelines for the minimum theoretical and applied training required for participation in an industrial electronics and robotics training program.

JUSTIFICATION

Robotics is not a new technology, in the broad sense of the term. Any mechanical device capable of performing routine tasks on command is considered a robot. From a technological standpoint, increased employment of robots by industry is based on the ability of robot manufacturers to provide mechanical devices that are compact, reliable, and easily programmable. With the development of new alloys, DC stepping motors, and the integrated circuit, robot manufacturers are now able to meet these requirements. In particular, the microprocessor and its associated support devices enable robots to be easily programmed and reprogrammed, leading to the expansion of robotics technology.

By 1990, industry will employ 250,000 robots.[1] Thus, students leaving secondary schools and adult vocational training programs are entering industrial environments that include a proliferating number of mechanical devices such as spot welders, numerically controlled tooling machines, and automated production line equipment. Trained workers will be needed to manufacture and service the robots. The person entering industry unprepared to operate and maintain these types of mechanical devices will be forced to accept the lowest levels of employment industry has to offer.

Futhermore, job creation within a geographic location in the future atmosphere of increasingly sophisticated electromechanical technology is facilitated by the presence of a technically well-trained work force. Competition from highly automated foreign industries is forcing American firms to adopt a higher level of automatation in order to remain profitable. Given the continually advancing technical nature of American business and industry, it is imperative that an adequately trained work force be provided. A trained work force is necessary not only to prevent firms within the state from closing, but also to attract new industries and jobs into the state. Only the public education system can provide the requisite training on a scale sufficient to ensure that Connecticut citizens will be able to find jobs upon leaving secondary schools or adult re-training programs.

Preliminary research indicated that two distinct sets of skills are required for 1) the operation and routine maintenance of industrical robots, and 2) robot repair and trouble-shooting. Operation and routine maintenance require no specific entry-level skills, while trouble-shooting and repair require extensive training in electro-mechanical technology to qualify for entry-level employment.

In order to develop a relevant and flexible curriculum consistent with the goals and philosophy of the Connecticut State Board of Education, and to fulfill the intentions of the Division of Vocational Education, two curriculums are needed. The State Department of Education explicates its goals in *A Guide to Curriculum Development*:

> There are very few unskilled jobs in the Connecticut economy and in the future even higher levels of proficiency will be necessary for employment and advancement in the high technology industries that will dominate the state's economy. Students will also need *transferable skills for occupational mobility and long term employment.*[2] [Emphasis added.]

A survey of manufacturing firms which either use or make industrial robots was undertaken for this project. This survey corroborated the conclusions of previous studies that employers prefer entry-level employees with broadly based job preparation and generic skills over those with job-specific skills. Employers desire workers with flexible skills so that employees can be assigned to different tasks within the company as the need arises. These findings underscore the need for emphasizing broad, transferable skills in curriculum development.

THE ROBOTICS CURRICULUM

To train students to meet the skill requirements of entry-level candidates for positions entailing maintenance, repair, and trouble-shooting of industrial robots, the curriculum provides a four-year program in electro-mechanical technology, culminating in a robotics course that will give students an opportunity to apply their training. The robotics course is designed so that it may also be offered independently as a separate course to students with no previous electro-mechanical training. The robotics course would be an appropriate offering for people seeking unskilled jobs in industries which utilize robots, providing an advantage to candidates for jobs involving the operation and routine maintenance of industrial robots.

Hence, the curriculum consists of several courses. The material covered includes Electronics I, Electronics II, Microprocessor Control Units, and Robotics. In addition, an outline of additional courses and prerequisites is included in a suggested sequence of courses for the four-year training program in electro-mechanical technology.

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1. State of Connecticut, Division of Vocational Education, *A Guide to Curriculum Development*, p. 8.

2. *Ibid.*, p. 7.

Each course is divided into units or sections, with objectives, contents, and suggested laboratory experiments specified for each. Criteria for student evaluation are found at the end of the curriculum, following the course offerings. The appendix includes text and reference sources, information about industries producing and/or employing industrial robots, and the results of a survey conduted to determine the entry-level skills expected by employers in the robotics industry.

Some prerequisite training is necessary for the student to successfully complete each course. The following outline provides a recommended sequence of courses which will provide the necessary theoretical and applied training and background required for the student to successfully participate in and complete the robotics curriculum.

First Year

1. DC and AC circuit Analysis
2. Survey course in Industrial Arts
3. Algebra I, Technical Algebra, or Algebra/Geometry

Second Year

1. Electronics (Transistor Circuit Theory)
2. Drafting I
3. Algebra II
4. 1/2 year course in Electromechanics
5. 1/2 year course in Hydraulics and Pneumatics

Third Year

1. 1/2 year course in Digital Electronics
2. 1/2 year course in Microprocessor Software, Hardware, and Interfacing
3. Drafting II
4. Math elective or computer programing

Fourth Year

1. Robotics
    A. Robot Fundamentals
    B. AC and Fluidic Power
    C. DC Power and Positioning
    D. Microprocessor Controllers
    E. Data Acquisition
    F. Data Handling and Conversion

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2. Automated Manufacturing
    A. Numerical Control
    B. Robotic Applications
        i. Low-Technology Robots
        ii. Medium-Technology Robots
        iii. High-Technology Robots
        iv. Automated System Servicing
3. Math elective or computer programming
4. Robotics Laboratory

The above courses are of one year duration unless otherwise indicated.

The next section of this report summarizes and analyzes the findings of the research conducted for this project.

SUMMARY AND CONCLUSIONS

PROJECT DESIGN

The purpose of this project was to conduct a research program designed to meet the stated objectives. Since the project was to develop an industrial electronics and robotics curriculum capable of successful implementation, an investigation into the following areas was undertaken:

1. A curriculum search was conducted at the levels of the secondary school, technical institute, and industrial training programs. This search was necessary to determine if any existing programs could be adopted for this project.

2. The industrial firms which produce robots and numerical control equipment were identified. This information was obtained through state agencies, industrial organizations, professional societies, engineers, and academic institutions, including the Ward Technical Institute and Waterbury State Technical College.

3. Literature related to industrial electronics and robotics was collected.

4. Manufacturers and employers of industrial robots were contacted.

5. The information collected in steps (1) to (4) was used to determine:
    A. The minimum entry-level training requirements in the robotics industry.
    B. Industrial training programs available for modification, inclusion or adaptation to meet the goals of this project.
    C. Sources of equipment supplies.

6. A professional group including representatives from industry and education was established to guide, review and critique the project.

RESEARCH RESULTS

Entry-Level Skills Assessment and Curriculum Implementation.

The robotics curriculum development project calls for an assessment of the entry level skills criteria for the robotics industry. A survey of selected robot manufacturers was conducted to determine the educational and skill levels acceptable for entry-level robot technicians. Of the 47 manufacturers for whom we have product information, twelve firms were interviewed. The firms produce all types of industrial robots, and have installed from one to 10,000 or more robots in industrial environments. The majority of industrial robots currently in use were produced by the companies participating in the survey.

Results of this survey indicate that robot manufacturers prefer to hire electronic/mechanical technicians with ASEE or ASME degrees, with two to five years experience in digital and microprocessor electronics. Employers will consider hiring students with the background outlined in question 5 of the survey. (The survey instrument is included in the appendix.) The results of this survey and the associated implications for successful implementation of the robotics curriculum below.

1. The robotics industry expects prospective employees to be well trained in electronics technology, electromechanical technology, and fluid power. Additional training in robotics and automated manufacturing technology is desirable. Thus, participation in an industrial electronics curriculum culminating in robotic applications is mandated.

A meeting with the Connecticut Commissioner of Economic Development reinforced these expectations. Industry is demanding qualified technical personnel. If Connecticut is to successfully attract and keep high technology industries, workers must be prepared to fill these jobs. To meet the demands of industry, therefore, the training or re-training programs must prepare the prospective employee to pass a professional competency exam in industrial electronics and robotics.

2. However, there are few robotics instructors in industry, and we know of none currrently in secondary education. Teacher training institutions in Connecticut do not offer the courses necessary to train teachers as robotics instructors. To implement the curriculum, robotics instructors must be attracted from industry or current secondary school teachers must be re-trained. Ideally, a robotics instructor should have a background in high technology and be knowledgeable in electronics (including programmable controllers and digital electronics), hydraulics, and mechanics.

A possible solution to the staffing problem is to implement the curriculum within an interdisciplinary framework. For example, an electronics teacher, a mechanics teacher, and an industrial arts instructor could each be trained to teach different segments of the curriculum. The problem of re-training secondary school teachers could be solved by taking advantage of the effective training programs often sponsored by robot vendors.

3. The industry representatives interviewed all stressed the practical aspects of robotics training programs. The importance of extensive hands-on experience with the tools and instruments used to assemble, test, repair, and maintain industrial robots was emphasized. The representatives recommended acquiring each type of robot manufactured for use in laboratory demonstrations.

4. Implementation of the curriculum on a regional basis is suggested due to the following considerations:

A. Projected low enrollment per school.
B. High program start-up costs.
C. Lack of qualified instructors.

A possible model for the program is the vocational agriculture program currently operating in the state.

6. Many students completing the course of study outlined in this curriculum may wish to pursue additional technical training. Therefore, the possibility of students receiving credit for participating in the robotics curriculum was discussed with faculty at Ward Technical College and Waterbury State Technical College. Both institutions have expressed strong interest in the program. Upon completion of this project, definite arrangements should be made to implement the curriculum in conjunction with post-secondary institutions.

Research Problems

Research was conducted to determine available curriculums, training programs, and supporting texts and reference materials. The major finding was that a dearth of relevant information exists. In particular, the following problems were encountered:

1. There is a lack of comprehensive training program data at the vendor, user, and secondary school levels. The secondary school programs currently available are designed to provide students with an introduction to the basic robot system. These programs do not provide comprehensive training to develop saleable entry-level skills in the robotics industry.

The vendors hold courses tailored to the end user's applications. Most vendors have not developed formal curriculums. At large robot installations, such as automobile assembly lines, the vendor supplies technical support on-site. For smaller installations, employees of the user firm are trained by the vendor to maintain, operate, and repair the robots.

2. There is a general lack of relevant text and reference materials which can be used in a comprehensive robotics program.

3. Adult re-training programs do not appear to be comprehensive. Programs operated by institutions such as the Cambridge Springs Skill Center in northwestern Pennsylvania require candidates to demonstrate competency in microprocessors, electronics, and digital logic before enrolling in the program.

CONCLUSIONS

Based on the research conducted for this project, the following conclusions are drawn, with recommendations for successful implementation of a robotics curriculum designed to provide meaningful job training skills:

1. A successful training program can be implemented at the secondary school level if the criteria for program initiation and maintenance are followed.

2. Post-secondary technical training institutions have indicated a willingness to participate in programs that will recognize technical training received at the secondary school level. The robotics curriculum should be implemented in conjunction with post-secondary technical training institutions.

3. Industry will accept secondary school graduates who can demonstrate successful completion of a technical program and can demonstrate proficiency via professional certification. The State of Connecticut could facilitate this process through the establishment of a certification board.

4. A general robotics familiarization course that focuses only on basic mechanical operation and maintenance skills will not qualify a worker for an entry-level position in the robotics industry. Examining the entry-level job requirements and job descriptions for a large robot manufacturing company, indicates that a substantial background in electronics technology is required. The job descriptions and corresponding skill requirements are included in the appendix.

All of the information obtained for this project indicates that robotics training programs designed to provide marketable skills must be comprehensive in nature.

A SECONDARY-LEVEL CURRICULUM IN INDUSTRIAL ELECTRONICS AND ROBOTICS

Prepared for the Connecticut State Department of Education
Division of Vocational and Adult Education
Bureau of Vocational Program Planning and Development
Hartford, CT 06115

Prepared by
Plymouth Board of Education
Terryville, CT 06786

Francis E. Besancon
Project Director
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All opinions expressed reflect the view of the author and are not necessarily those of the State Department of Education.

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ELECTRONICS I: AC AND DC FUNDAMENTALS

Introduction

Electronics I is the introductory course in a four-year electronics technology program designed to provide secondary school students with the knowledge and skills required to successfully seek employment in the electronics industry. The course is also designed to prepare secondary students for participation in post-secondary technical training programs.

This course provides students with a firm foundation in AC/DC circuit analysis. The first part covers basic circuit concepts, definitions and analysis of resistive circuits with DC energy sources. The second part includes time-varying voltages, reactive components, and the analysis of reactive networks with AC energy sources. Throughout the course, concepts are illustrated with laboratory exercises and demonstrations of practical applications. A substantial amount of time is to be spent in the laboratory developing skills in the use of electronic instruments, hand tools, and circuit construction.

Course Objectives

Upon mastery of the material presented in this course, the student will have developed the skills necessary to:

1. Describe the structure of matter to the atomic level.

2. Describe the electric field, electical potential energy, and the volt.

3. Discuss the relationship between voltage, resistance, current, and power.

4. Describe the resistance property of materials, the standard identification methods for resistors, and the types of resistors used in the industry.

5. Apply Ohm's Law, Kirchoff's Laws, and the power rule to the analysis of electrical networks.

6. State the characteristics of a voltage and current source. Convert a voltage source to a current source and vice versa.

7. Apply the Superposition Theorem, Thevenin's Theorem, Norton's Theorem, and Millman's Theorem to the solution of electrical network problems.

8. State the Maximum Transfer Theorem.

9. Make delta-wye and wye-delta network conversions.

10. Use the branch current method, mesh current method and node voltage method to analyze electrical circuits.

11. Describe and measure the characteristics of electrical signals.

12. Describe and measure the electrical and mechanical characteristics of capacitance.

13. Describe and measure the fequency response of RC circuits.

14. Describe and measure the pulse response of RC circuits.

15. Describe and measure the electrical and mechanical characteristics of inductance.

16. Describe and measure the electrical and mechanical characteristics of inductance.

17. Describe and measure the pulse response of RL circuits.

18. Describe the operation, construction, and application of transformers.

19. Apply the complex number system to reactive circuits.

20. Describe resonance.

21. Describe and measure the characteristics of filters.

22. Construct AC and DC electrical networks from schematic diagrams. Analyze these networks using appropriate theories and electrical instruments.

23. Operate a VOM, VTVM, function generator, variable power supplies, period and frequency meters, and the oscilloscope.

24. Interpret the measurements obtained by using the instruments listed in 23.

25. Use trouble-shooting techniques to locate problems in AC and DC electrical networks.

26. Repair the problems uncovered by trouble-shooting.

Course Content

Unit One: Introduction

I. Objectives.

Upon mastery of the material presented in this unit, the student will have developed the skills necessary to:

1. Briefly discuss the history and general application of electronics.

2. State the international system of units and quantities for electronics.

3. Use scientific notation to represent large and small quantities.

II. Content.

1. The historical time line for development of electrical theory and the individuals associated with these developments.

2. Applications of electronics.
    A. Computers.
    B. Communications systems.
    C. Automation.
    D. Medicine.
    E. Consumer products.

3. International system of electrical units.

4. Scientific notation.
    A. Powers of 10.
    B. Calculations using powers of 10.
        i. Rules of addition.
        ii. Rules of subtraction.
        iii. Rules of multiplication.
        iv. Rules of division.
    C. Metric prefixes.

III. Laboratory Experiments.

There are no laboratory experiments recommended for this unit. The following demonstrations would serve as appropriate illustrations of the material presented in this unit:

1. Demonstrate the use of electronics equipment from the computer, medical and industrial fields, e.g.
    A. Personal computer.
    B. ECG Transducer.
    C. Thermocouple.

UNIT TWO: ATOMIC STRUCTURE, ENERGY, VOLTAGE, CURRENT, AND RESISTANCE

I. Objectives.

This unit will provide the student with the skills necessary to:

1. State Coulomb's Law.

2. Describe the characteristics of a scalar and vector field; specifically, the characteristics of the electrical field.

3. Describe the structure of the Bohr model of the atom.

4. Define the terms:
    - A. Atomic weight and number.
    - B. Shells.
    - C. Valance band and conduction band.
    - D. Free electrons.

5. Describe the concepts of work and energy, and explain their relationship to one another.

6. Define the term current, give its unit of measure, and calculate the magnitude of a current, using measures of time and change.

7. Define the term voltage, give its unit of measure, and calculate the magnitue of a voltage, using measures of energy and change.

8. Define the term resistance, give its unit of measure, and describe its relationship to conductance.

9. Describe the construction and electrical characteristics of carbon composition resistors, metal film resistors, and variable resitors.

10. Use the resistance color code to determine the value in Ohms of the resistor and its tolerance.

11. Describe the electrical characteristics of insulators, semiconductors, and conductors.

12. Describe the construction and electrical characteristics of thermistors and photo conductive cells.

13. Describe the American wire gauge standard and the relationship between the resistance of a wire and its length, cross section area, and resistivity.

14. Construct and evaluate the electrical behavior of a simple electrical circuit.

15. Describe the electrical characteristics of a closed, an open and a short circuit.

16. Use a VOM, VTVM and DMM to measure electrical parameters.

17. Describe the mechanical construction and electrical behavior of a switch, a fuse and a circuit breaker.

II. Content.

1. Atom.
   - A. Models of the atom.
   - B. Atomic weight and atom number.
   - C. Valance and conduction band.
   - D. The copper atom.
   - E. Free electrons.

2. Work and energy.
   - A. Definition of work.
   - B. Definition of energy.
     - i. Potential.
     - ii. Kinetic.

3. Voltage.
   - A. Definition.
   - B. Unit.
   - C. The voltage source.
   - D. Formula for voltage.

4. Current.
   - A. The unit of charge.
   - B. Definition of current.
   - C. The ampere.

5. Resistance.
   - A. Definition.
   - B. Unit.
   - C. Ohm.
   - D. Resistance symbol.
   - E. Conductance.
     - i. Formula for conductance.

6. Types of resistors.
   - A. Fixed resistors.
   - B. Carbon-composition fixed resistors.
   - C. Deposited-film resistors.
   - D. Variable resistors.
   - E. Thermistors and photo-conductive cells.

7. Conductors, semiconductors, and insulators.
   - A. Definition of each.
   - B. Electrical characteristics of each.

8. Wire size.
    A. American wire gauge.
    B. Factors affecting wire resistance.

9. The electric circuit.
    A. Electrical characteristics of open and closed circuits.
    B. Electrical characteristics of short circuits.

10. Measurement.
    A. Meter symbols.
    B. Measuring current.
    C. Measuring voltage.
    D. Measuring resistance.

11. Circuit protective devices.
    A. Fuses.
        i. Plug type.
        ii. Cartridge type.
    B. Circuit breakers.
        i. Magnetic.
        ii. Thermal.
    C. Switches.
        i. SPST.
        ii. SPDT.
        iii. DPST.
        iv. DPDT.
        v. Push-button switches.
        vi. Rotary switches.
        vii. Electronic switches (multiplexers).

III. Laboratory Experiments and Demonstrations.

A. Demonstrations.

1. Demonstrate the operation of the VOM, VTVM, and DMM, emphasizing:
    A. Switch and control settings for measurement of voltage and resistance on the VTVM.
    B. Switch and control settings for measurement of voltage, current and resistance on the VOM and DMM.
    C. Proper placement of instrument leads in relation to polarity and the measurement of voltage and current.

2. Demonstrate the use of the color code to identify resistance and the operation of variable resistances.

3. Demonstrate the operation of the three standard types of circuit protective devices.

4. Demonstrate the materials and methods used to construct simple prototype circuits.

B. Laboratory work.

Each laboratory experiment is designed to aid the student in developing the skills and knowledge necessary to meet the objectives of the unit.

Objective	Experiment Title	Purpose
7,8,9,14	Resistance.	1. To identify the resistance of a resistor using the color code. 2. To identify and measure the electrical characteristics of potentiometers, photoconductive cells, and thermistors. 3. To prepare the VOM, DMM and VTVM to measure resistance. 4. To determine if a given resistance is within its tolerance.
11,13,14	Voltage measurement.	1. To prepare the VTVM, VOM and DMM to measure DC voltage. 2. To practice the skills needed to construct prototype electrical networks. 3. To measure the electrical parameters of short, open, and closed circuits.
14,15	Circuit protective devices.	1. To determine the electrical characteristics of a circuit protective device.

UNIT THREE: OHM'S LAW, ENERGY AND POWER, AND KIRCHOFF'S LAW

I. Objectives.

Upon mastery of the material presented in this unit, the student will have developed the skills necessary to:

1. State Ohm's Law, and use it to calculate voltage, current, or resistance, given two of three equation variables.

2. State and apply the power rule.

3. Determine the power rating of a resistor.

4. Discuss the relationship between energy loss and voltage drop.

5. State Kirchoff's Law.

6. Apply Kirchoff's Law to a series circuit.

7. State the electrical characteristics of a series circuit.

8. State the electrical characteristics of a voltage divider. Use the voltage divider to determine the voltage distribution in a series circuit.

9. State the characteristics of open and closed circuits.

10. Trouble-shoot series electrical networks.

II. Content.

1. Ohm's Law.

2. Characteristics of the series circuit.
   A. Total resistance.
   B. Identification of resistors connected in series.
   C. Current flow in a series circuit.

3. Ohm's Law applications.

4. Voltage sources connected in series.

5. Kirchoff's Voltage Law.

6. Voltage dividers.
   A. Voltage divider formula.
   B. The potentiometer as a voltage divider.
   C. Voltage divider applications.

7. Power distribution in a series circuit.

8. Characteristics of open and closed circuits.

9. Troubleshooting a series circuit.

III. Laboratory Experiments.

The laboratory exercises are designed to develop the student's skills in breadboarding, component identification, electrical measurements with the DMM, VTVM, and VOM, and verification of electrical theory.

Objective	Experiment Title	Purpose
1,9,10	Measuring currents.	1. To demonstrate the proper method of connecting an ampmeter in an electrical network. 2. To demonstrate the use of a voltmeter and resistor to measure current.
1,7	Verifying Ohm's Law.	1. To verify Ohm's Law.
2,3	Power.	1. To verify the Power Equation.

UNIT FOUR: PARALLEL CIRCUITS

I. Objectives.

Upon mastery of the material presented in this unit, the student will have developed the skills necessary to:

1. State the electrical characteristics of a parallel circuit.

2. Identify resistors corrected in parallel.

3. Specify the voltage drop across the branches of a parallel circuit.

4. Calculate and measure the total resistance for a parallel circuit.

5. Calculate and measure voltage drop and current flow in a parallel circuit.

6. Describe the effet of current sources connected in parallel.

7. State and apply Kirchoff's Current Law.

8. Describe the characteristics of a current divider.

9. Apply the current divider equation to multiple path networks.

10. Describe the effects of open and shorted components located in a parallel circuit.

11. Troubleshoot a parallel circuit.

II. Content.

1. Resistors connected in parallel.
    - A. Rule for identifying resistors connected in parallel.

2. Voltage drop in a parallel circuit.

3. Total resistance of a parallel network.
    - A. Effect of resistors connected in parallel.
    - B. Effect of conductances connected in parallel.
    - C. Formula for total parallel resistance.
    - D. Formula for resistance of two resistors in parallel.
    - E. Total resistance of equal valued resistors in parallel.
    - F. Method for determining an unknown parallel resistance.

4. Current sources connected in parallel.

5. Kirchoff's Current Rule.

6. Current dividers.
    - A. General current divider formula.
    - B. Current divider formula for two resistors in parallel.

7. Power in a parallel circuit.

8. Effects of open and shorted parallel paths.

9. Troubleshooting a parallel electrical network.

III. Laboratory Experiments.

The laboratory exercises are designed to develop the students' skills in breadboarding parallel circuits, component identification, verifying parallel circuit theory, and electrical measurements with the DMM, VOM, and VTVM.

Objective	Experiment Title	Purpose
1,2,4	Measuring parallel circuit resistance.	1. To verify the equations for the resistance of two resistors in parallel and the equations for more than two resistors in parallel. 2. To develop skill in breadboarding electrical networks from schematic diagrams.
3,4 5,7	Measuring the electrical characteristics of a parallel circuit.	1. To verify the calculations of voltage and current for a parallel circuit.

		2. To verify Kirchoff's Law.
7,8,9	Current dividers.	1. To use the current divider formula to predict branch current. 2. To verify predicted measurements.
10,11	Troubleshooting parallel networks.	1. To measure the electrical characteristics of an open and shorted parallel branch circuit. 2. To develop general troubleshooting procedures.

UNIT FIVE: SERIES-PARALLEL NETWORKS

I. Objectives.

Upon mastery of the material presented in this unit, the student will have developed the skills necessary to:

1. Define a series-parallel circuit.

2. Given a schematic diagram, identify those components that are connected in series and parallel.

3. Determine voltage drop, current flow, and power consumption for individual components in a series-parallel circuit.

4. Define circuit ground.

5. Troubleshoot a series-parallel circuit.

6. Design a voltage divider with a resistance load.

7. Describe the operation of a Weatstone Bridge.

II. Content.

1. Definition of a series-parallel circuit.

2. Identification of a series-parallel circuit.

3. Analysis of series-parallel circuits.
   - A. Calculation of total resistance.
   - B. Determination of total current.
   - C. Determination of branch current.
   - D. Calculation of voltage drops.

4. Circuit ground.
   - A. Measurement of voltage with respect to ground.
   - B. Measurement of voltage across an ungrounded resistor.

5. Voltage dividers.
   - A. Unloaded voltage dividers.
   - B. Loaded voltage dividers.
   - C. Design of voltage dividers.

6. Weatstone Bridge.
   - A. Operation.
   - B. Use as an ohm meter.

7. Troubleshooting a series-parallel network.

III. Laboratory Work.

Objective	Experiment Title	Purpose
1,2,3,4	Analysis of a series-parallel circuit.	1. To verify the methods used to predict total resistance, total current, branch currents, and individual and branch voltage drops.
4,7	Voltage dividers.	1. To illustrate that circuit ground is an arbitrary reference point for the measurement of voltage.
		2. To design and evaluate an unloaded voltage divider.
		3. To design and evaluate a loaded voltage divider.
8	Weatstone Bridge.	1. To illustrate the electrical behavior of a Weatstone Bridge.
		2. To demonstrate the method used to design a Weatstone Bridge.

UNIT SIX: CIRCUIT THEOREMS AND ANALYTICAL METHODS

I. Objectives.

Upon mastery of the material presented in this unit, the student will have developed the skills necessary to:

1. State the characteristics of an ideal voltage and current source.

2. Convert a voltage source to a current source and a current source to a voltage source.

3. State the Superposition Theorem.

4. Determine the electrical parameters for a multiple energy source circuit using the Superposition Theorem.

5. State Thevenin's Theorem.

6. Determine the electrical parameters for a multiple energy source circuit using Tevenin's Theorem.

7. State Norton's Theorem.

8. Determine the electrical parameters for a multiple energy source using Norton's Theorem.

9. State Millman's Theorem.

10. Determine the equivalent voltage source for any number of parallel voltage sources using Millman's Theorem.

11. State and apply the Maximum Power Transfer Theorem.

12. Convert Delta resistance networks to Wye resistance networks and Wye networks to Delta networks.

13. Apply Kirchoff's Current and Voltage Laws to the analysis of resistive multiple voltage source electrical networks.

14. Use determinants to solve the simultaneous equations developed when using Kirchoff's Laws to analyze multiple voltage source electrical networks.

15. Use the computer to determine the electrical parameters for a multiple voltage source electrical network.

II. Content.

1. The voltage source.
    A. Characteristics of the ideal voltage source.
    B. Characteristics of the loaded voltage source.

2. The current source.
    A. Characteristics of the ideal current source.
    B. Characteristics of the loaded current source.

3. Energy source conversions.
    A. Conversion from a voltage source to a current source.
    B. Converting from a current source to a voltage source.

4. The Superposition Theorem.

5. Thevenin's Theorem.
    A. Meaning of Equivalency.
    B. Thevenin's Equivalent Voltage (V_{Th}).
    C. Thevenin's Equivalent Resistance (R_{Th}).
    D. Determining Thevenin's V_{Th} and R_{Th} by measurement.

6. Norton's Theorem.
    A. Norton's Equivalent Current (I_N).
    B. Norton's Equivalent Resistance (R_N).

7. Millman's Theorem.
    A. Millman's Equivalent Voltage.
    B. Millman's Equivalent Resistance.

8. Maximum Power Transfer Theorem.

9. Delta-Wye and Wye-Delta network conversions.

10. Kirchoff's Laws applied to multiple voltage source circuits.

11. Use of second and third order determinants to solve network problems.

III. Laboratory Experiments.

Objectives	Experiment Title	Purpose
1 through 8	Circuit analysis.	1. To verify the calculations of circuit parameters made using Thevenin's Theorem, Norton's Theorem, and Kirchoff's Laws.
11	Maximum Power Transfer.	1. To verify the Maximum Power Transfer Theorem.
15	Computer-aided solutions.	1. To introduce the student to basic computer operation and technology. 2. Use of the microcomputer to solve simultaneous equations.

UNIT SEVEN: SIGNAL CHARACTERISTICS AND ANALYSIS

I. Objectives.

Upon mastery of the material presented in this unit, the student will have developed the skills necessary to:

1. State the characteristics of a sine wave of voltage.

2. Use the equation for the sine wave to determine the frequency, period, peak voltage, and instantaneous voltage of a specific sine wave.

3. Graph a sine wave of voltage.

4. Use the oscilloscope to measure the period, peak voltage, and instantaneous voltage of a sine wave.

5. State the relationship between frequency and period.

6. Calculate the following amplitude values of a sine wave when given one amplitude measurement:
    A. RMS voltage.
    B. Average voltage.
    C. Peak voltage.
    D. Peak-to-peak voltage.

7. State the relationship between voltage, current, power, and resistance for an AC circuit.

8. Measure the phase relationship between AC signals.

9. Describe the ideal characteristics of pulse wave forms.

10. Measure and calculate the following characteristics of non-ideal pulse wave forms:
    A. Rise time and fall time.
    B. Pulse width.
    C. Pulse repetition rate or frequency.
    D. Percent duty cycle.
    E. Average value.

11. Describe the following characteristics of triangular and saw-tooth wave forms:
    A. Slope.
    B. Period.

12. Describe the term harmonics and explain how harmonics of a fundamental frequency can be combined to produce other wave forms.

13. Describe the operation of an oscilloscope at the block diagram level.

14. Explain how cathode ray tubes can be used to display an electrical signal.

15. Explain the term synchronization.

16. Describe the functions of the switches and controls used to operate a general purpose oscilloscope.

17. Measure the electrical characteristics of wave forms with an oscilloscope.

II. Content.

1. Characteristics of the sine wave.
    A. Frequency.
    B. Period.
    C. Amplitude.

2. Amplitude measures for a sine wave.
    A. Peak voltage.
    B. Peak-to-peak voltage.
    C. Average voltage.
    D. RMS (effective) voltage.

3. Ohm's Law in AC circuits.

4. Operation of a general purpose oscilloscope.

5. Measures of period, frequency, peak, and peak-to-peak voltage on the general purpose oscilloscope.

6. Phase relationships.
    A. Angular measurement.
    B. Phase angle measurement with an oscilloscope.

7. Equation for a sine wave.
    A. General equation for a sine wave.
    B. Equations for phase shifted sine waves.

8. Phasors.
    A. Phasor representation of a sine wave.
    B. Phasors and the sine wave formula.
    C. Positive and negative phasor angles.
    D. Phasor diagrams.
    E. Angular velocity of a phasor.

9. Pulse wave forms.
    A. Characteristics of an ideal pulse wave form.
    B. Characteristics of a non-ideal pulse wave form.
        i. Pulse width.
        ii. Pulse rise time and fall time.

C. Repetitive pulses.
    i. Frequency.
    ii. Period.
    iii. Percent duty cycle.
    iv. Square waves.
    v. Average value of a pulse wave form.

10. Triangular and sawtooth wave forms.
    A. Ramps
        i. Slope of a voltage ramp.
        ii. Slope of a current ramp.
    B. Triangular waves.
    C. Sawtooth waves.

11. Harmonies.
    A. Fundamental frequency.
    B. Odd and even harmonies.
    C. Composite wave forms.

III. Laboratory Experiments.

Objective	Experiment Title	Purpose
1,2,3,4,5, 6,7,16,17, 18	Measuring AC voltages	1. To demonstrate how an AC voltmeter and an AC ampmeter are uaed to measure AC voltages and currents. 2. To demonstrate how an oscilloscope is used to measure voltage, period, and frequency. 3. To demonstrate the relationship between AC voltage and currents in a resistive circuit.
8,15,16,17	Measuring frequency and phase angle with an oscilloscope.	1. To demonstrate the methods of measuring frequency and phase angle with an oscilloscope.
10 and 11	Pulse wave forms.	1. To demonstrate the method of measuring pulse width, period, and amplitude for a non-ideal pulse on a general purpose oscilloscope. 2. To demonstrate the method of measuring the slope of a ramp voltage on an oscillocope.

UNIT EIGHT: CAPACITANCE

I. Objectives.

Mastery of the material presented in this unit will provide the student with the skills necessary to:

1. Define capacitance.

2. Describe the physical attributes of a capacitor that determine capacitance.

3. Describe the charging and discharging of a capacitor.

4. Apply the relation: Capacitance = Charge/Voltage.

5. Calculate the total capacitance of capacitors.

6. Calculate the voltage drop and charge distribution in a capacitance network.

7. Explain the most common ways in which capacitors fail.

8. Describe the phase relationship between the voltage and current in a capacitive circuit.

9. Draw a diagram that represents the phase relationship between the current and voltage in a capacitive circuit.

10. Define capacitive reactance and determine its value in ohms.

11. Use Ohm's law to calculate current flow in a capacitive circuit.

12. Discuss energy and power relationships in a pure capacitive circuit.

13. Determine if a capacitor is within tolerance.

II. Content.

1. Basic capacitor.
    - A. Structure.
    - B. Electrical field.
    - C. Charging and discharging a capacitor.
    - D. Unit of capacitance.

2. Characteristics of capacitance.
    A. Identification.
    B. Voltage rating.
    C. Plate area.
    D. Dilectric constant.
    E. Dilectric strength.
    F. Temperature coefficient.
    G. Leakage.

3. Types of capacitors.
    A. Mica capacitors.
    B. Ceramic capacitors.
    C. Paper capacitors.
    D. Electrolytic capacitors.
    E. Film capacitors.
    F. Integrated circuit capacitors.

4. Capacitor labeling.
    A. Color coding.

5. Series capacitors.
    A. Total capacitance.
    B. Two capacitors in series.
    C. Capacitors of equal value in series.
    D. Capacitor voltages.

6. Parallel capacitors.
    A. Total capacitance.

7. Phase relationship of capacitive voltage and current.

8. Capacitive reactance.
    A. Definition of capacitive reactance (X_C).
    B. Ohm's Law in reactive circuits.

9. Energy and power in a capacitor.
    A. Energy stored in a capacitor.
    B. Average power.
    C. Reactive power.

10. Test capacitors.
    A. Ohmmeter test.
    B. Capacitance meter.

III. Laboratory Experiments.

Objectives	Experiment Title	Purpose
5,13	Capacitance Fundamentals.	1. To observe the basic properties of capacitors.
5,6	Series/Parallel Capacitive Circuits.	2. To observe the voltage distribution in a series and parallel capacitive circuit.

UNIT NINE: FREQUENCY RESPONSE OF RC CIRCUITS

I. Objectives.

Mastery of the material presented in this unit will provide the student with the skills necessary to:

1. Discuss what is meant by the sine wave response of an RC circuit.

2. Define trigonometric functions in terms of the sides of a triangle.

3. Write trigonometric relationships to solve for one side of a triangle, given an angle and another side.

4. Relate the unit circle and the sine wave graphs to each other in terms of the sine of the angle of a rotating vector.

5. Read values of trigonometric functions from angles from 0° through 90° from tables.

6. Solve right triangles consisting of electrical phasors by using trigonometric functions.

7. Calculate the impedance of a series RC circuit and show the phase relationship between R and X_C.

8. Calculate the phase angle for a series RC circuit from its resistance and capacitive reactance.

9. State how the phase angle of an RC circuit varies with frequency, resistance, and capacitive reactance.

10. Apply Ohm's Law to a series RC network.

11. Discuss the application of an RC network as a high pass and low pass filter.

12. Calculate the power factor for an RC circuit and the actual power consumed by an RC circuit.

13. Discuss the basic parallel RC circuit.

14. Draw the phasor diagram for a parallel RC circuit.

15. Calculate the phase angle for a parallel RC network.

16. Calculate the currents flowing in the branches of a parallel RC circuit.

17. Calculate the impedance of a parallel RC circuit.

18. Use an oscilloscope to measure phase angle and voltage distribution in RC networks.

19. Use a DMM and VOM to measure voltage distribution and current flow in an RC network.

II. Content.

1. Sine wave response.

2. Basic trigonometry.

3. Impedance of a series RC circuit.

4. Phase angle.
   - A. Definition of the term "phase angle".
   - B. Methods of calculating the phase angle.
   - C. Methods of measuring the phase angle.
     - i. Measure voltage drops and calculate the phase angle.
     - ii. Oscilloscope methods.
   - D. Phase angle magnitude variations.
     - i. With capacitance.
     - ii. With resistance.

5. Ohm's Law applied to series RC circuits.

6. The series RC network used as a filter.
   - A. High pass filter.
   - B. Low pass filter.
   - C. R-C coupling.

7. Power distribution in RC circuits.
   - A. Power triangle.
   - B. Power factor.

8. Circuit parameters for parallel RC circuits.
   - A. Total current.
   - B. Phase angle.
   - C. Impedance.

III. Laboratory Experiments.

Objectives	Experiment Title	Purpose
2,3,4,5,6,7, 8,12,13,14,	Trigonometric fundamentals.	1. To practice finding the sine, cosine, tangent, arc sine, arc cosine, and arc tangent of angles. 2. To practice calculating the unknown sides and angles of right triangles.

		3. To predict voltage drops, phase angles, and power distribution for RC circuits.
9,10,11,18,19	The response of RC and parallel networks to an AC voltage.	1. To practice three methods of measuring phase angles with an oscilloscope.
		2. To verify the calculated parameters that represent the behavior of an RC circuit.
11	The RC circuit as a filter.	1. To measure the frequency response of an RC circuit when used as a high pass and low pass filter.
		2. To verify the behavior of RC couplings.

UNIT TEN: PULSE RESPONSE OF RC CIRCUITS

I. Objectives.

Mastery of the material presented in this unit will provide the student the skills necessary to:

1. Describe the following pulse characteristics:
    - A. Leading and trailing edges of a pulse.
    - B. Overshoot and undershoot.
    - C. Ringing.
    - D. Tilt.

2. Discuss in general the concept of time constant.

3. Measure the time constant of an RC network.

4. Explain the charging and discharging of a capacitor in terms of the time constant for the circuit.

5. Discuss the characteristics of an exponential curve.

6. Apply the formula for exponential curves to an RC circuit.

7. Predict the response of an RC integrated circuit to a pulse input and a periodic pulse wave form.

8. Predict the response of an RC differentiation circuit to a pulse input and a periodic pulse wave form.

9. Discuss the current flow in an integrator and a differentiator.

10. Explain the relationship of time response to frequency response.

II. Content.

1. Pulse characteristics.
   - A. Leading edges.
   - B. Trailing edges.
   - C. Overshoot.
   - D. Ringing.
   - E. Tilt.

2. Time constant.
   - A. General description of time constants.
   - B. Applying time constants to RC networks.
   - C. Charging and discharging time constants.
   - D. Applications of the Universal Time Constant Chart.

3. Exponential curves.
   - A. General formula for exponential curves.
   - B. Equations for instantaneous voltage drop and current flow in an RC circuit.

4. The RC integrator.

5. The RC integrator's response to a rectangular pulse.
   - A. Variation of ouput wave shape with pulse width.

6. The RC integrator's response to periodic wave forms.

7. The RC differentiator's response to a rectangular pulse.
   - A. Variation of output wave shape with pulse width.

8. The RC differentiator's response to a periodic pulse wave form.

9. The relationship of time responses to frequency response.

III. Laboratory Experiments.

Objective	Experiment Title	Purpose
1	Measurement of pulse characteristics.	1. To measure and identify the following characteristics of pulse wave forms with an oscilloscope: a. Leading and trailing edges. b. Overshoot. c. Ringing. d. Tilt.
2,3,4,5,6	Charging and discharging capacitors.	1. To verify that an RC time constant is equal to R*C.

		2. To verify that the transient time for an RC circuit is 5*R*C. 3. To predict and measure the values of voltage drop and current flow in an RC circuit using the appropriate exponential equation.
7,8,9	RC integrator and differentiation circuits.	1. To examine the step and pulse response of a series RC circuit. 2. To examine the response of an RC circuit to a periodic pulse train. 3. To observe the effect of the pulse frequency on the response.

UNIT ELEVEN: INDUCTANCE

I. Objectives.

Mastery of the material presented in this unit will provide students with the skills necessary to:

1. Discuss the concept of the magnetic field and the reason that magnetic fields are observed.

2. State the characteristics of magnetic fields.

3. Describe the effect that a magnetic field has on a moving charged particle.

4. Describe how magnetic fields can be altered by the presence of different types of materials.

5. Define the terms magnetic flux and magnetic flux density.

6. Discuss electromagnetism.

7. Define magnetmotive force, reluctance, and permeability.

8. Explain electromagnetic induction.

9. State Faraday's Law.

10. Discuss self inductance.

11. State the characteristics of inductance.

12. State the characteristics of inductors.

13. Determine the total inductance for series connected inductors.

14. Determine the total inductance for parallel connected inductors.

15. State the phase relationship between inductive current and voltage.

16. Describe the characteristics of inductive reactance.

17. Discuss the behavior of inductors in DC circuits.

18. Discuss the relationship between energy and power for an inductor.

19. State the procedure for checking an inductor.

II. Content.

1. Characteristics of magnetic fields.
    A. Cause of magnetic fields.
    B. Magnetic materials.
    C. Flux.
    D. Flux density.
    E. Effect of magnetic fields on charged particles.

2. Electromagnetism.
    A. Magnetic fields around current-carrying wires.
    B. Right hand rule.

3. Electromagnetic properties.
    A. Magnetmotive force.
    B. Reluctance.
    C. Permeability.

4. Electromagnetic induction.
    A. Polarity of the induced voltage.
    B. Induced current.
    C. Effect of the magnetic field on current carrying conductors.

5. The inductor.

6. Faraday's Law.

7. Self inductance.
    A. Induced voltage dependence on the rate of change of the current.

8. Characteristics of inductors.
    A. Core materials.
    B. Physical factors.
    C. Winding resistance.
    D. Winding capacitance.

9. Types of inductors.

10. Series inductance.

11. Parallel inductance.

12. Phase relationship between inductance, current, and voltage.

13. Inductive reactance.

14. Inductors in DC circuits.

15. Energy and power in an inductor.

16. Testing inductors.

III. Laboratory Experiments.

Ojectives	Experiment Title	Purpose
12,13,18	Inductance Fundamentals	1. To observe and measure the basic properties of inductance.

UNIT TWELVE: FREQUENCY RESPONSE OF RL CIRCUITS

I. Objectives.

Mastery of the material presented in this unit will provide the student with the skills necessary to:

1. Describe, calculate, and measure the phase relationships between the applied voltage, V_L, and V_R for a series RL circuit.

2. Calculate the inductive reactance of an inductor and explain the relationship between inductive reactance and frequency.

3. Calculate the impedance of an RL circuit.

4. Calculate the phase angle of an RL circuit.

5. Discuss how the phase angle of an RL circuit is affected by frequency, inductance, and resistance.

6. Calculate voltage and current magnitudes for a series RL network.

7. Discuss the electrical parameters for RL lead and lag networks.

8. Measure the electrical parameters for RL lead and lag networks.

9. Discuss the electrical parameters for a series RL network used as low pass and high pass filters.

10. Measure the frequency response for high pass and low pass filters.

11. Discuss power distribution in an RL network.

12. Discuss the electrical parameters of a parallel RL network.

13. Calculate circuit phase angles, impedance, and current distribution in a parallel RL circuit.

II. Content.

1. Electrical parameters that represent a series RL circuit.
   A. Impedance.
      i. Calculation of inductive reactance (X_L).
      ii. Calculation of impedance (Z).
      iii. The impedance triangle.
   B. Voltage distribution.
      i. Calculation of voltage drops.
      ii. The voltage triangle.
   C. Current.

2. Circuit phase angle.
   A. Calculation of circuit phase angle.
   B. Phase angle variations with:
      i. Frequency.
      ii. Inductance.
      iii. Resistance.

3. The RL lead and lag networks.

4. The series RL circuit as a filter.
   A. Low pass filter frequency response.
   B. High pass filter frequency response.

5. Power in an RL circuit.

6. The parallel RL circuit.
   A. Calculation of impedance.
   B. Calculation of current distribution.
   C. Calculation of circuit phase angle.

III. Laboratory Experiments.

Objectives	Experiment Title	Purpose
1,2,3,4,5,6	Series RL network analysis.	1. To calculate and measure the voltage distribution and phase angle for a series RL circuit.

UNIT THIRTEEN: PULSE RESPONSE OF RL CIRCUITS

I. Objectives.

Mastery of the material presented in this unit will provide students with the ability to:

1. Discuss the concept of time constant in general and explain how the concept of a time constant is used in the study of RL circuits.

2. Calculate the time constant for an RL circuit.

3. Discuss the concept of transient time relative to an RL circuit.

4. Calculate the transient time for an RL circuit.

5. Describe the electrical characteristics of an RL circuit during the period in which a magnetic field is being established around an inductor and when the magnetic field is decaying to zero.

6. Calculate the instantaneous values of voltage and current in a series RL circuit during its transient time.

7. Sketch the voltage wave forms that would be observed across the resistive and inductive components of an RL integrator and differentiator.

8. Discuss the relationship between time response and frequency response for high pass and low pass RL filters.

II. Content.

1. Time constant and transient time.
    A. Calculation of time constant.
    B. Calculation of transient time.
    C. Voltage and current characteristics for an RL circuit during the transient time.
    D. Calculation of instantaneous voltage and current values during the transient time.

2. The RL integrator.

A. Comparison of the input voltage pulse to the output voltage wave form for an RL circuit connected as an integrator.

B. Methods of predicting the output voltage wave shape for an RL integrator.

3. The RL differentiator.

A. Comparison of input voltage pulses to ouput voltage wave forms for an RL circuit connected as a differentiator.

B. Methods of predicting the output voltage wave shape for an RL differentiator.

4. The relationship between time response and frequency rsponse for an RL circuit.

A. Using the integrator as a low pass filter.
B. Using the integrator as a high pass filter.

III. Laboratory Experiments.

Objectives	Experiment title	Purpose
1,2,3,4,5	RL time constants.	1. To develop a method for measuring the transient time for an RL circuit. 2. To calculate and measure voltages in an RL circuit during its transient time.
7,8	RL integrators and differentiators.	1. To observe and record the output and input voltage wave forms, measured with an oscilloscope, for an RL circuit. 2. To develop a frequency response curve for an RL integator and differentiator.

UNIT FOURTEEN: TRANSFORMERS

I. Objectives.

Mastery of the material presented in this unit will provide the student with the skills necessary to:

1. Discuss the mutual inductance of coils and the factors that affect it.

2. Calculate the mutual inductance of two coils.

3. Describe the construction of a basic transformer.

4. State the mechanical factors affecting the operation of a transformer.

5. State the dot convention for a transformer.

6. Calculate the turns ratio for a transformer.

7. State three methods of determining the turns ratio for a transformer.

8. Describe the operation of a step-up transformer.

9. Describe the operation of a step-down transformer.

10. Calculate the output voltage for a transformer given its input voltage and turns ratio.

11. Describe the effect on the transformer when a load is connected to the secondary.

12. Describe reflected impedance and the transformer characteristic which determines it.

13. Describe impedance matching and the advantage of matching a load impedance to the source impedance.

14. Describe how a transformer can be used as an isolation device.

15. Describe the operation of a tapped transformer.

16. Describe the operation of a multi-winding transformer.

17. Describe the operation of an auto transformer.

II. Content.

1. Mutual inductance.
    A. Coefficient of coupling.
    B. Formula for mutual inductance.

2. Basic transformer operation.
    A. Construction.
    B. Turns ratio.
    C. The effect on polarity of the direction of coil windings.
    D. Dot convention for transformer polarity determination.

3. Step-up transformer operation.
    A. Construction.
    B. Turns ratio.

4. Step-down transformer operation.
    A. Construction.
    B. Turns ratio.

5. Secondary loading.
    - A. Current relationships.
    - B. Power relationships.
    - C. Reflected impedance.
    - D. Impedance matching.

6. The use of a transformer as an isolation device.

7. Tapped transformers.

8. Multi-winding transformers.
    - A. Construction.
    - B. Operation.

9. Auto transformers.

III. Laboratory Experiments.

Objectives	Experiement Title	Purpose
1	Induced EMF.	1. To study the EMFs induced in conductors that result from changes in the magnetic flux linking the conductors.
3,4,5,6,7	Transformer fundamentals.	1. To study the mechanical factors which affect the operation of a transformer. 2. To study the electrical characteristics of a transformer. 3. To verify voltage and turns ratio relationships in a transformer.
11,12,13	Impedance matching.	1. To demonstrate impedance matching using a transformer.

UNIT FIFTEEN: COMPLEX NUMBERS: APPLICATIONS IN REACTIVE CIRCUITS

I. Objectives.

Mastery of the material presented in this unit will provide students with the skills necessary to:

1. Discuss real and imaginary numbers.

2. Define the real and imaginary axes and the j operator.

3. Represent angles on the complex plane.

4. Represent a point on the complex plane.

5. Use complex numbers to represent phasor values in polar and rectangular form.

6. Convert polar coordinates to rectangular coordinates and vice versa.

7. Add, subtract, multiply, and divide complex numbers.

8. Represent resistance, reactance, and impedance in complex form.

9. Apply the rules of complex number arithmetic to the solution of RCL series, parallel, and series-parallel electrical circuits.

II. Content.

1. Complex numbers.
    A. The complex plane.
    B. Representing a point on the complex plane.
    C. The j operator and its value.

2. Polar and rectangular coordinates.
    A. Phasor values represented in polar and rectangular format.
    B. Polar to rectangular and rectangular to polar conversion.

3. The arithmetic of complex numbers.
    A. Addition.
    B. Subtraction.
    C. Multiplication.
    D. Division.

4. The representation of resistance, reactance, and impedance using complex numbers.
    A. Resistance representation.
    B. Reactance representation.
    C. Impedance representation in polar and rectangular forms.
    D. Calculation of impedance in series and parallel RC and RL circuits.

5. Impedance in RCL circuits.
    A. Calculation of impedance in series RCL circuits.
    B. Calculation of impedance in parallel RCL circuits.
    C. Calculation of conductance, susceptance, and admittance for series and parallel RCL circuits.

6. Analysis of reactive circuits.

7. Series equivalent circuits.

III. Laboratory Experiments.

Objectives	Experiment Title	Purpose
7,8,9	The series RCL circuit.	1. To examine voltage, current, and impedance relationships in a series RCL circuit.

UNIT SIXTEEN: RESONANCE

I. Objectives.

Mastery of the material presented in this unit will provide students with the skills necessary to:

1. State the characteristics of resonance for a series circuit and a parallel circuit.

2. Calculate the resonant frequency.

3. Define the term "bandwidth."

4. Given a series resonant circuit, calculate the bandwidth.

5. Given a parallel resonant circuit, calculate bandwidth.

6. Define the term "selectivity."

7. Discuss the quality factor of a resonant circuit.

8. Calculate and measure the "Q" of a coil.

II. Content.

1. Resonance.
    A. Series resonance.
        i. Definition of series resonance.
        ii. Calculation of the resonant frequency for a series circuit.
        iii. Voltage and current distribution in a series resonant circuit.
        iv. Impedance of a series circuit at resonance.
        v. Phase characteristics of a series RCL circuit.

B. Parallel resonance.
   i. Definition of parallel resonance.
   ii. Calculation of the resonant frequency for a parallel circuit.
   iii. Voltage and current distribution in a parallel circuit.
   iv. Impedance of a parallel circuit.

2. Bandwidth.
   A. Definition of bandwidth.
   B. Formula for bandwidth.
   C. Half-power frequencies.
   D. Selectivity.

3. Quality of a resonant circuit.
   A. Definition of "Q".
   B. Effect of "Q" on voltage distribution in a series RCL circuit.
   C. The effect of "Q" on bandwidth.

III. Laboratory Experiments.

Objective	Experiment Title	Purpose
1,2,3,4,5	Series resonance.	1. To investigate the characteristics of a series resonant circuit. 2. To show that the resonant frequency of a series RCL circuit is 1/2 pi*LC. 3. To plot the frequency response of an RCL circuit.
1,2,3,4,5	Parallel resonance.	1. To investigate the characteristics of a parallel resonant circuit. 2. To show that the resonant frequency of a parallel RCL circuit is 1/2 pi*LC.
1,2,3,4,5	Q of a coil.	1. To use a resonant circuit as a means of finding the Q of a coil.

UNIT SEVENTEEN: FILTERS

I. Objectives.

Mastery of the material presented in this unit will provide students with the skills necessary to:

1. Discuss the electrical characteristics of low pass and high pass filters.

2. Sketch the representative frequency response curves for high pass and low pass filters.

3. Discuss the electrical characteristics of band stop and band pass filters.

4. Sketch the representative frequency response curves for band stop and band pass filters.

5. Express the frequency response of a filter in terms of the decibel (dB) measurement.

II. Content.

1. Low pass filters.
    A. Definition of the range of frequencies that constitute the pass band.
    B. Commonly used low pass circuits.
    C. Inverted-L, T-type, and pi-type low pass filters.

2. High pass filters.
    A. Definition of the range or frequencies that constitute the pass band.
    B. Commonly used high pass filter circuits.
    C. Inverted-L type, T-type, and pi-type high pass filters.

3. Band pass filters.
    A. Band pass filter response curve.
    B. Series resonant band pass filters.
    C. Parallel resonant band pass filters.

4. Band stop filters.
    A. Band stop filter response curve.
    B. Series resonant band stop filters.
    C. Parallel resonant band stop filters.

5. Filter response characteristsics.
    A. Decibel measurement.
    B. -3dB frequencies.
    C. Equation for determining cut-off frequencies.
    D. Frequency response "roll-off" curve.

III. Laboratory Experiments.

Objectives	Experiment Title	Purpose
1	AC coupling and bypassing.	1. To determine how a capacitor is to couple an AC signal from one circuit tc another. 2. To determine how a capacitor can bypass an AC signal around a circuit component. 3. To apply the superposition principle to a circuit containing both AC and DC voltages.
1,2	LC filters.	1. To determine the frequency characteristics of high and low pass filters.
3,4	Band pass and band stop filters.	1. To determine the frequency characteristics of series and resonant band stop and band pass filters. 2. To determine the frequency response characteristics of parallel resonant band stop and band pass filters.

UNIT EIGHTEEN: TEST EQUIPMENT

Portions of this unit have been introduced at appropriate times during the presentation of the course material. Specifically, the sections on instrument controls and applications are covered in the sections of the course in which the use of the instrument is relevant.

I. Objectives.

Mastery of the material presented in this unit will provide students with the skills necessary to:

1. Describe the operation of d'Arsonual, taut-band, electrodynamometer, concentric vane, thermocouple, and electrostatic meter movements.

2. Explain how AC may be measured with a d'Arsonual meter movement.

3. Calculate the value of a shunt resistor used to extend the range of an ampmeter.

4. Explain the operation of a simple voltmeter.

5. Calculate the value of a multiplier resistor used to extend the range of a voltmeter.

6. Describe a process that can be used to measure the sensitivity of a voltmeter.

7. Explain how the loading effect can cause measurement errors.

8. Explain how high input impedance is achieved in an electronic meter.

9. Identify the various parts of a cathode ray tube from a drawing of the CRT and state their functions.

10. Describe how the electron beam is deflected within the CRT.

11. Define deflection sensitivity.

12. Define bandwidth.

13. State the difference between the horizontal and vertical deflection circuits.

14. State the purpose of blanking and unblanking.

15. State the difference between triggered and free-running sweeps. State the advantages and disadvantages of each.

16. State the purpose of a sweep magnifier.

17. State how a delayed sweep functions.

18. State the differences between a chop and alternative presentations of a dual trace.

19. State the applications of a sampling oscilloscope.

20. Explain the purpose of each control on a general purpose oscilloscope.

21. Describe a procedure for measuring AC and DC voltages on an oscilloscope.

22. Describe a procedure for measuring time and frequency on an oscilloscope.

23. Describe a procedure for measuring phase and frequency using Lissajous figures on an oscilloscope.

II. Content.

1. Meter movement construction and operation.
   - A. d'Arsonual movement.
   - B. Taut-band movement.
   - C. Electrodynamometer.
   - D. Concentric-vane movement.
   - E. Thermocouple movement.
   - F. Electrostatic meter movement.

2. Measuring AC with a rectifier-type d'Arsonual meter.

3. The ampmeter.
   - A. Construction of a multi-range ampmeter.
   - B. Determining the value of shunt resistances.
   - C. Scales.
     - i. Linear scales.
     - ii. Nonlinear scales.
   - D. Meter accuracy.
   - E. Connecting an ampmeter in a circuit.

4. Clamp-on meters.
   - A. Construction.
   - B. Operation.
   - C. Electrical characteristics.

5. Construction of the ampmeter section of a VOM.

6. Factors affecting the selection of a meter.
   - A. Accuracy.
   - B. Sensitivity.
   - C. AC measurement.
   - D. Resistance.
   - E. Physical characteristics.
   - F. Cost.

7. The voltmeter.
   - A. Range of a voltmeter.
   - B. A method of extending the range of a voltmeter.
   - C. Determining the value of a multiplying resistor.
   - D. Construction of multi-range voltmeters.
   - E. Voltmeter sensitivity.
   - F. Loading effect of voltmeters.
   - G. Voltmeter accuracy.
   - H. Connecting a voltmeter properly in a circuit.

8. Operation of a typical voltmeter.
   - A. AC voltmeter operation.
   - B. DC voltmeter operation.

9. Voltmeter scales.
    A. DC scale.
    B. AC scale.
        i. RMS scale.
        ii. P-P scale.
    C. Decibel scale.

10. Factors affecting the selection of a voltmeter.
    A. Types of voltages to be measured (AC, DC, or both).
    B. Whether the AC meter requires a true RMS measurement.
    C. Range of voltages to be measured.
    D. Necessity of a dB scale.
    E. Sensitivity.
    F. Cost.

11. The ohmmeter.
    A. The basic ohmmeter circuit.
    B. Calibration of the ohmmeter scale.
    C. Extending the range of the ohmmeter.
    D. Series vs. shunt ohmmeters.
    E. Ohmmeter accuracy.
    F. Measuring resistance in a circuit.
    G. Ohmmeter scales.

12. Operation of a typical ohmmeter section of a VOM.

13. Construction and operation of a typical VOM.

14. Overview of the oscilloscope's measuring ability.
    A. Types of measurement.

15. Functional block diagram of an oscilloscope.
    A. Vertical system overview.
    B. Trigger system overview.
    C. Horizontal system overview.
    D. Display system.

16. Initializing the oscillosope (preparing the oscilloscope for use).
    A. Display system controls.
    B. Vertical system controls.
    C. Horizontal system controls.
    D. Trigger system controls.

17. Function of the display system and the purpose of the display system controls.
    A. Function of the display system.
    B. Beam finder control.
    C. Intensity control.
    D. Focus control.
    E. Trace rotation control.
    F. Using the display controls.

18. Function of the vertical system and the purpose of the vertical system controls.
  A. Function of the vertical system.
  B. Purpose of the vertical position control.
  C. Purpose of the input coupling switch.
  D. Purpose of the vertical sensitivity control.
  E. Purpose of the variable volts/div. control.
  F. Purpose of the inversion control.
  G. Vertical operating mode control.
    i. Single channel operation.
    ii. Both channels in chopped or alternative mode.
    iii. Both channels algebraically summed.
  H. Alternate sweep separation.

19. Function of the horizontal system and the purpose of the horizontal system controls.
  A. Function of the horizontal system.
  B. Purpose of the horizontal position control.
  C. Purpose of the horizontal operating mode control.
  D. Purpose of the horizontal sweep spread control.
  E. Purpose of the horizontal magnification control.
  F. Purpose of the horizontal variable sec/div. control.
  G. Purpose of the horizontal delayed time and multiplier controls.

20. Function of the trigger system and the purpose of the triggering controls.
  A. Function of the triggering system.
  B. Purpose of the trigger level and slope controls.
  C. Purpose of the variable trigger hold-off control.
  D. Purpose of the trigger source switch.
  E. Purpose of the trigger operating mode control.
  F. Purpose of the trigger coupling control.

21. Probes.
  A. Purpose of a probe.
  B. Probe characteristics.
    i. Circuit loading.
    ii. Measurement system bandwidth.
    iii. Probe termination.

22. Measurements.
  A. Wave forms.
    i. Definition of a wave.
    ii. Definition of a wave form.
    iii. Basic wave shapes and characteristics.
      a. Sine wave.
      b. Square wave.
      c. Triangular wave.
      d. Sawtooth wave.
      e. Pulse wave.
      f. Step wave.

iv. Basic measurements with the oscilloscope.
  a. Amplitude.
  b. Period.
  c. Frequency.
  d. Rise time of a pulse.
  e. Fall time of a pulse.
  f. Period of a pulse.
  g. Pulse width.
  h. Duty cycle of a rectangular wave.
  i. Duty factor of a rectangular wave.
  j. Repetition rule of a rectangular wave.
  k. Phase.

23. Safety.
  A. General rules.
  B. Scope use.

III. Laboratory Experiments.

Objectives	Experiment title	Purpose
20	Initializing the scope.	1. To locate the controls associated with the functional block diagram.
		2. To set the controls for initial scope operation.
20	Display system controls.	1. To review the location and function of the display system controls.
		2. To use the display system controls to produce a usable trace on the scope screen.
20	Vertical system controls.	1. To compensate the probe for use with the scope.
		2. To provide familiarity with the vertical system controls.
20	Horizontal system controls.	1. To provide familiarity with the with the horizontal system controls.
15	Trigger controls.	1. To review triggering.
		2. To provide familiarity with trigger controls.

20,22,23	Measuring techniques.	1. To measure the amplitude of a wave form on the scope.
		2. To measure the period or pulse width of a wave form on the scope.
		3. To measure rise and fall time of a pulse.
		4. To make delayed sweep measurements of rise time and pulse width.

ELECTRONICS II: CONTROL DEVICES AND CIRCUIT THEORY

Introduction

The AC and DC fundamentals course (Electronics I) is the prerequisite for this course. Electronics I provides the student with the theoretical knowledge and laboratory skills needed to explain the electrical characteristics of resistance, capacitance, and inductance. Electronics II provides the student with the theoretical knowledge and laboratory skills needed to understand the operation of solid state and vacuum tube devices and the fundamental design techniques used in developing electronic networks.

Course Objectives

Upon mastery of the material presented in this course, the student will have developed the skills necessary to:

1. Describe the electrical characteristics of materials which are classified as semiconductors.

2. Name the primary advantages that semiconductor devices have over vacuum tubes.

3. Explain how the most important semiconductor devices operate.

4. Describe how the most important semiconductor devices operate.

5. Handle semiconductor components properly without exceeding their maximum ratings or damaging them with improper handling procedures.

6. Recognize the most commonly used semiconductor packages.

7. Recognize the schematic symbols used to represent a wide variety of semiconductor devices.

8. Test various semiconductor devices to determine if they are functioning properly.

9. Identify basic transistor amplifier circuits, describe their operation, and list the characteristics of each.

10. Discuss direct current amplifiers, audio amplifiers, video amplifiers, intermediate frequency amplifiers, and radio frequency amplifiers, including their application in practical electronic systems.

11. Explain the operation of differential amplifiers, comparators, summing and difference amplifiers, and active filter circuits.

12. Analyze and design simple inverting and non-inverting amplifiers that use operational amplifiers.

13. Identify and explain the operation of power supply rectifiers, filters, and regulation circuits.

14. Discuss the basic principles of oscillation, identifying and describing the operation of commonly used LC, RC, and crystal oscillators.

15. Demonstrate a knowledge of pulse shapers, multivibrators, the Schmidt trigger, and ramp generators.

16. Explain amplitude and frequency modulation, the heterodyne principle, and modulation and detection circuits.

17. Construct transistor and integrated circuit amplifiers, oscillators, active filters, and pulse-shaping circuits; power supplies and power supply regulation circuits; and basic amplitude modulation and demodulation systems.

18. Use a voltmeter and a oscilloscope to analyze the operation of electronic circuits.

COURSE CONTENT

UNIT ONE: SEMICONDUCTOR FUNDAMENTALS

I. Unit Objectives.

Upon mastery of the material presented in this unit, the student will have developed the skills necessary to:

1. Name three common semiconductor devices.

2. Describe the basic function of semiconductors in electronic equipment.

3. Describe the electrical characteristics of materials which are classified as semiconductors.

4. Name the two most commonly used semiconductor materials.

5. Explain the difference between intrinsic and doped semiconductors.

6. Define the word "hole" as it applies to semiconductors.

7. Explain how electrical current flows through intrinsic and doped semiconductors.

8. Name five advantages of semiconductor devices over other components with similar capabilities.

II. Content.

1. The importance of semiconductors:
    A. Advantages.
    B. Disadvantages.

2. Semiconductor materials:
    A. Germanium.
    B. Silicon.
    C. Semiconductor crystals.

3. Conduction in intrinsic Germanium and Silicon:
    A. Low temperature characteristics.
    B. High temperature characteristics.
    C. Holes in semiconductor materials.
    D. Current flow in semiconductor materials.

4. Conduction in doped Germanium and Silicon:
    A. N-Type semiconductors.
    B. P-Type semiconductors.

UNIT TWO: SEMICONDUCTOR DIODES

I. Objectives

Upon mastery of the material presented in this unit, the student will have developed the skills necessary to:

1. Describe the basic construction of a semiconductor diode.

2. Draw a schematic diagram showing the proper forward and reverse biasing of a semiconductor diode.

3. Explain the forward and reverse charcteristics of a semiconductor diode.

4. Interpolate the graphicaly plotted voltage-current characteristics for any given diode.

5. Identify two different diode packages.

6. Test diodes with a ohmmeter to determine if they are functioning properly.

7. List four key applications for semiconductor diodes.

II. Content.

1. The PN Junction.

2. Ions.

3. Junction Diodes.
    A. Depletion region.
    B. Junction potential (Barrier voltage).

4. Diode biasing.
    A. Forward bias.
    B. Reverse bias.

5. Diode characteristics.
    A. Germanium diode characteristics.
        i. Forward characteristics.
        ii. Reverse characteristics.
    B. Silicon diode.
        i. Forward characteristics.
        ii. Reverse characteristics.

6. Diode Ratings.

7. Diode temperature considerations.

8. Diode symbols.

9. Diode construction.
    A. Grown junctions.
    B. Alloyed junctions.
    C. Diffused junctions.

10. Diode packaging.

11. Diode applications.
    A. Rectification.
    B. Other applications for diodes.
        i. Clippers.
        ii. Clampers.

III. Laboratory Experiments.

Objectives	Experiment Title	Purpose
	The curve tracer.	1. To become familiar with the operation of a curve tracer. 2. To interpret the volt-ampere characteristic curves obtained with a curve tracer.
3,4,5	Characteristics of semi-conducting devices.	1. To measure the characteristics of a solid state diode.

		2. To develop the characteristic curves (V-A curves) for a solid state diode using: a. A volt meter and an amp meter. b. A curve tracer.
6	Testing semiconductor diodes.	1. To develop a practical method of testing semiconductor diodes.

UNIT THREE: THE ZENER DIODE

I. Objectives.

Upon mastery of the material presented in this unit, the student will have developed the skills necessary to:

1. Describe the forward and reverse current-voltage characteristics of a typical zener diode

2. Understand the relationship between temperature and zener diode power dissipation.

3. Determine a zener diode's maximum safe operating current.

4. Use a diode's impedance to determine the amount of change that can occur in the diode's zener voltage.

5. Describe how the zener diode is used to provide voltage regulation.

6. Design a zener regulator circuit.

II. Content.

1. Zener diode characteristics.
    A. Voltage-Current characteristics.
    B. Zener voltage.

2. Power dissipation in zener diodes.
    A. Power-temperature curves.
    B. Derating factor.

3. Current limitations in zener diodes.

4. Effects of temperature on zener voltage.

5. Temperature-compensated zener diodes.

6. Zener diode impedance.

7. Zener diode packages.

8. Voltage regulation with zener diodes.

9. The basic zener diode regulator.

10. Designing a zener regulator circuit.

III. Laboratory Experiments.

Objectives	Experiment Title	Purpose
1,2,3,4	Zener diode characteristics.	1. To observe the volt-ampere characteristic curves for a zener diode on a curve tracer.
		2. To interpret manufacturers' specification sheets for a zener diode.
5,6	Zener diode applications.	1. To demonstrate the use of a zener diode as a voltage regulator.
		2. To demonstrate the use of a zener as a simple square wave generator.
		3. To design, construct, and evaluate a voltage regulation circuit, using a zener diode.

UNIT FOUR: SEMICONDUCTOR DIODES FOR SPECIAL APPLICATIONS

I. Objectives.

Upon mastery of the material presented in this unit, the student will have developed the skills necessary to:

1. Locate the peak current, valley current, peak voltage, and valley voltage points on a tunnel diode's V-I curve.

2. Describe the negative resistance characteristics of a tunnel diode.

3. Recognize three commonly used tunnel diode symbols.

4. Describe how capacitance is produced within a varactor diode.

5. Describe how a varactor's internal capacitance and Q are affected by a change in operating voltage.

6. Recognize three commonly used varactor diode symbols.

7. Name four special diode types other than the tunnel and varactor diodes and state an application for each.

8. Describe the construction and operation of a photo tube.

9. Describe the spectral response of a photo tube in relation to the wave length of the incident light.

10. For a given wave length of light, describe the photo tube's volt-ampere characteristic curves.

11. Describe the construction, operation, and characteristics of a semiconductor photo conductive cell and photo diode.

12. Describe the construction, operation, and characteristics of a light emitting diode.

13. Describe the construction, operation, and characteristics of a liquid crystal display.

14. Describe the construction, operation, and characteristics of a solar cell.

15. Describe the construction, operation, and characterisitics of a thermistor.

II. Content.

1. The tunnel diode.
    A. Voltage-current characteristics.
    B. Negative resistance.
    C. Construction.
    D. Applications.

2. The varactor diode.
    A. Electrical characteristics.
    B. Operating efficiency.
    C. Construction.
    D. Applications.

3. High frequency diodes.
    A. PLN diodes.
    B. IMPATT diodes.
    C. Hot carrier diodes.
    D. Gunn-effect diodes.

4. Photo tubes.
    A. Construction.
    B. Operation.
    C. Electrical characteristics.
    D. Applications.

5. Semiconductor photo conductive cell and photo diode.
    A. Construction.
    B. Operation.
    C. Electrical characteristics.
    D. Applications.

6. Light emitting diodes.
    - A. Construction.
    - B. Operation.
    - C. Electrical characteristics.
    - D. Applications.

7. Liquid crystal displays.
    - A. Construction.
    - B. Operation.
    - C. Electrical characteristics.
    - D. Applications.

8. Solar cells.
    - A. Construction.
    - B. Operation.
    - C. Electrical characteristics.
    - D. Applications.

9. Thermistors.
    - A. Construction.
    - B. Operation.
    - C. Electrical characteristics.
    - D. Applications.

III. Laboratory Experiments.

Objectives	Experiment Title	Purpose
12	Characteristics and operation of light emitting diodes.	1. To demonstrate the relationship between diode forward curent and LED intensity.
		2. To demonstrate the design principles used for an LED display.
12	7-segment LED displays.	1. To demonstrate the operation of a 7-segment LED display.
11	Photo cells.	1. To demonstrate the effects of the intensity and wave length of light on photo cells.
		2. To demonstrate applications for a photo cell.

Application of a PIM diode as an optical detector.	1. To demonstrate the effects of light intensity and reverse voltage on the ouput of a PIM diode. 2. To demonstrate the light sensitivity of a PIM diode. 3. To compare the electrical characteristics of a PIM diode and phototransistor devices.

UNIT FIVE: BIPOLAR TRANSISTOR AND VACUUM TUBE OPERATION

I. Objectives.

Upon mastery of the material presented in this unit, the student will have developed the skills necessary to:

1. Describe the basic construction of the two basic types of bipolar transistors.

2. Describe the basic principles behind bipolar transistor operation.

3. Describe basic transistor amplifying action.

4. Demonstrate proper biasing for normal transistor operation.

5. Describe the relationship between emitter current, base current, and collector current in a bipolar transistor.

6. Identify and describe the operation of the three basic amplifier arrangements.

7. Describe the construction, operation, and electrical characteristics of vacuum tube diodes, triodes, tetrodes, and pentodes.

II. Content.

1. PNP and NPN configurations.

2. Transistor construction.
    A. Construction techniques.
    B. Packaging.

3. Basic transistor action.
    A. Biasing NPN transistors.
    B. Biasing PNP transistors.

4. Transistor amplification.

5. Transistor circuit arrangements.
    A. Common base circuits.
    B. Common emitter circuits.
    C. Common collector circuits.

6. Testing bipolar transistors.
    A. Test procedures.
    B. Testing NPN transistors.
    C. Testing PNP transistors.
    D. Identifying a transistor.

III. Laboratory Experiments.

Objectives	Experiment Title	Purpose
2,4	Testing bipolar transistors.	1. To demonstrate the use of an ohm meter to test NPN and PNP bipolar transistors.
6	Basic amplifier arrangements.	1. To demonstrate the operation and characteristics of the common-emitter, common-base, and common-collector amplifiers.

UNIT SIX: DC BIASING

I. Objectives.

Upon mastery of the material presented in this unit, the student will have developed the skills necessary to:

1. Discuss the need for biasing a control device and the general concepts underlying biasing.

2. Define the term "operating point" and discuss the considerations behind the choice of a particular operating point.

3. State a procedure for designing a common-base (CB) bias circuit.

4. State the general bias considerations for a common-emitter (CE) circuit connection.

5. Describe a procedure for designing a fixed bias circuit for a CE amplifier.

6. Define the terms "bias stabilization" and "stability factor".

7. Describe the operation of a DC bias circuit incorporating emitter stabilization.

8. Design a DC bias circuit for an amplifier, using emitter stabilization.

9. Describe the operation of a DC bias circuit that is independent of beta.

10. Design a DC bias circuit for an amplifier that is beta independent.

11. Describe the operation of an amplifier that uses voltage feedback for DC bias stabilization.

12. Design an amplifier using voltage feedback for DC bias stabilization.

13. Describe bias techniques for a common-collector (emitter-follower) DC bias circuit.

14. Design a beta-stabilized emitter-follower DC bias circuit.

15. Describe a method for graphically finding the operating point of a biased transistor circuit.

16. Describe the DC bias of vacuum tube circuits.

17. Given a vacuum tube or transistor amplifier, determine the type of DC biasing used and calculate the voltage distribution for the circuit.

18. Given a defective single stage vacuum tube or transistor amplifier, determine the defective component.

II. Content.

1. General DC biasing considerations.

2. General considerations for selecting an operating point.

3. Common base bias circuits.
    A. Input section.
    B. Output section.

4. Common emitter bias considerations.
    A. Fixed bias circuit operation.
    B. Calculation of the bias point for a fixed bias circuit.
        i. Input section.
        ii. Output section.
        iii. Transistor saturation.

5. Bias stabilization.
    A. Stability factor.
    B. Calculating stability factors for parameters affecting bias stability.

6. Common DC bias circuits for a CE amplifier.
   A. Current feedback (emitter stabilization).
      i. Input section (base-emitter loop).
      ii. Output section (collector-emitter loop).
   B. DC bias circuit independent of beta.
   C. Voltage feedback.
      i. Input section.
      ii. Output section.
   D. Current and voltage feedback DC bias circuits.

7. Common-collector DC bias circuits.
   A. Emitter-follower bias circuit.
      i. Input section.
      ii. Ouput section.
   B. Beta-stabilized emitter-follower DC bias circuit.

8. Graphical DC bias analysis.

9. DC bias of vacuum tube circuits.
   A. Triode amplifier circuit.
   B. Pentode amplifier circuit.

10. Design of DC bias circuits.
   A. Design considerations.
      i. Design point (operating point).
      ii. Bias circuit.
      iii. Supply voltage.
   B. Design of a fixed bias circuit.
   C. Design of a current feedback circuit.
   D. Design of a beta-stabilized circuit.
   E. Design of a voltage feedback circuit.

11. Analysis of miscellaneous bias circuits.

12. Troubleshooting single stage amplifiers.

III. Laboratory Experiments.

Objectives	Experiment Title	Purpose
	Transistor volt-ampere characteristic curves.	1. To obtain the volt-ampere characteristic curves for NPN and PNP transistors.
		2. To interpret the manufacturer's specification sheet for a given transistor.
3	DC bias circuit for a CB amplifier.	1. To design, construct, and evaluate a CB amplifier.

4 through 12	DC bias circuits for a CE amplifier.	1. To design, construct, and evaluate a CE amplifier, using the following DC bias techniques: A. Current feedback. B. Voltage feedback. C. Beta stabilized. D. Voltage-current feedback.
14,15	DC bias circuits for a CC (emitter-follower) amplifier.	1. To design, construct, and evaluate an emitter-follower amplifier, using current feedback.
18	Troubleshooting a single-stage amplifier.	1. To develop a troubleshooting procedure. 2. Given a single-stage defective amplifier, to isolate the defective component and repair the unit.

UNIT SEVEN: SIGNAL CIRCUIT ANALYSIS

I. Objectives.

Upon mastery of the material presented in this unit, the student will have developed the skills necessary to:

1. Develop the equivalent circuit for common base, common collector, and common emitter amplifiers from basic two-part theory.

2. State the hybrid equations most often used in transistor circuit analysis and show how these equations are used to draw an equivalent electronic network that represents a transitorized electronic network.

3. Define the hybrid parameters and calculate these values from the transistor characteristic curves obtained from a curve tracer.

4. Describe how the hybrid parameters vary with variations in temperature, frequency, junction potential, etc.

5. Interpret the variations in the hybrid characteristics using normalized curves.

6. Analyze the basic transistor amplifier using the hybrid equivalent circuit.

7. Develop the equations for current gain, voltage gain, power gain, output impedance and input impedance utilizing the hybrid equivalent circuit.

8. Analyze the AC operation of the basic amplifier networks using the hybrid equivalent circuit.

9. Analyze the AC operation of the basic amplifier networks using approximations frequently applied when using the hybrid equivalent circuit and its related equations.

10. Describe the effect that loads and signal sources located in other parts of the circuit will have on the base, collector or emitter potential and current, using approximate base, collector, and emitter equivalent circuits.

11. Describe and analyze the basic amplifier networks using a DC operating parameter and the hybrid parameters.

12. Analyze the triode, tetrode, and pentode vacuum tube amplifiers using a small signal equivalent circuit.

II. Content.

1. Transistor hybrid equivalent circuit.

2. Graphical determination of the h-parameters.

3. Variations of the h-parameters.

4. Small-signal analysis of the basic transistor amplifier using the hybrid equivalent circuit.

5. Approximations frequently applied when using the hybrid equivalent circuit and its related equations.

6. Approximate base, collector and emitter equivalent circuits.

7. An alternative approach to circuit analysis.

8. Collector feedback.

9. Summary table.

10. The triode small-signal equivalent circuit.

11. Triode parameter variation.

12. The pentode small-signal equivalent circuit.

III. Laboratory Experiment.

Objectives	Experiment Title	Purpose
2,3,4,5	Measuring hybrid transistor parameters.	1. To obtain the input and ouput volt-ampere characteristic curves for NPN or PNP transistors using a curve tracer.

		2. To calculate h_{fe}, h_{oe}, h_{ie}, and h_{re} for the transistors using the characteristic curves obtained from the curve tracer.
8,9,10,11	Analyzing the AC operation of an amplifier.	1. To analyze the AC operation of an amplifier, using the hybrid equivalent circuit. 2. To describe the AC operation of a basic amplifier, using a DC operating parameter and the hybrid parameters.

UNIT EIGHT: FIELD-EFFECT TRANSISTORS

I. Objectives.

Upon mastery of the material presented in this unit, the student will have developed the skills necessary to:

1. Describe the operation of a junction field effect transistor and a metal-oxide semiconductor field effect-transistor.

2. Describe the construction and electrical behavior of a J-FET.

3. Describe the operation of a basic J-FET amplifier using self bias.

4. Describe the construction and electrical characteristics of a depletion and enhancement MOSFET.

5. Design a basic depletion and enhancement MOSFET amplifier using self bias.

6. Describe DC bias using the universal J-FET bias curve.

7. Describe the AC small signal operation of a J-FET and MOSFET amplifier.

8. Describe the electrical operation of the source-follower amplifier.

9. Describe high and low frequency effects in a FET.

10. Describe the operation of a bootstrap source follower circuit.

11. Design a FET amplifier.

12. Design a FET to operate as a voltage variable resistor.

13. State the applications of a VVR.

II. Content.

1. General description of a FET.
2. Construction and electrical characteristics of a J-FET.
3. DC bias of a J-FET.
4. MOSFET construction and electrical characteristics.
5. MOSFET DC bias circuit.
6. DC bias using the universal J-FET bias curve.
7. AC small signal amplifier operation.
8. High and low frequency effects in FET.
9. Bootstrap source-follower circuit.
10. Design of FET amplifier circuits.
11. The FET as a voltage variable resistor.

III. Laboratory Experiments.

Objectives	Experiment Title	Purpose
2,3,6,11,12	Junction FET (J-FET) characteristics and applications.	1. To obtain the J-FET drain and transfer characteristics. 2. To demonstrate the design and operation of a typical J-FET amplifier. 3. To design a FET circuit to act as a voltage variable resistor.
4,5,6,11	Insulated gate FET characteristics and applications.	1. To obtain the V-A characteristics for an insulated gate transistor. 2. To demonstrate the design and operation of a typical insulated gate transistor.

UNIT NINE: TYPICAL AMPLIFIERS

I. Objectives.

Upon mastery of the material presented in this unit, the student will have developed the skills necessary to:

1. Explain the function and operation of DC, audio, video, power, RF, and IF amplifiers.

2. Identify the Darlington arrangement an explain how it operates.

3. Describe how a basic differential amplifier can be used to amplify a single input signal and explain why the circuit offers a high degree of thermal stability.

4. Identify three types of power amplifiers.

5. Explain how volume and tone can be controlled in an audio amplifier.

6. Describe how the video amplifier obtains its wide bandwidth.

7. List three ways of increasing the bandwidth in RF and IF amplifiers.

8. Explain the basic differences between IF and RF amplifiers.

9. Describe the purpose of neutralization.

10. Explain how a frequency multiplier works.

II. Content.

1. Direct current amplifiers.
    A. Basic circuit configuration.
    B. Multi-stage amplifiers.
    C. Darlington amplifiers.
    D. Differential amplifiers.

2. Audio amplifiers.
    A. Voltage amplifiers.
    B. Basic power amplifiers.
    C. Single-ended power amplifiers.
    D. Push-pull power amplifiers.
    E. Complementary amplifiers.
    F. Quasi-complementary amplifiers.
    G. Heat sinks.
    H. Volume control circuits.
    J. Tone control circuits.

3. Video amplifiers.

        A. Factors affecting frequency response.
        B. Frequency compensation.
        C. Typical video amplifier.

    4. RF and IF amplifiers.
        A. Tuned amplifiers.
        B. Amplifier neutralization.
        C. Typical RF amplifiers.
        D. Frequency multipliers.
        E. IF amplifiers.

III. Laboratory Experiments.

Objectives	Experiment Title	Purpose
1,2	DC amplifiers.	1. To demonstrate how the input resistance of an amplifier is affected by the beta of the transistor and emitter resistor. 2. To demonstrate how beta can be increased with the Darlington circuit.
1,4	Complementary power amplifiers.	1. To demonstrate the operation of a power amplifier commonly used in many small radios, televisions, and phonographs. 2. To demonstrate two different types of distortion and to identify the type of distortion when heard on a speaker or viewed on an oscilloscope.
1,4	Transformer-coupled audio power amplifier.	1. To observe the operation of a power amplifier. 2. To calculate and measure the voltage distribution and current flow in a power amplifier.
1,4	Push-pull power amplifiers.	1. To demonstrate the operation of a push-pull power amplifier.
1,3	The differential amplifier.	1. To observe the operation of a differential amplifier.

UNIT TEN: MULTISTAGE SYSTEMS, DECIBELS (DB), AND FREQUENCY CONSIDERATIONS

I. Objectives.

Upon mastery of the material presented in this unit, the student will have developed the skills necessary to:

1. Describe the general electrical characteristics of cascaded systems.

2. Analyze the frequency response of RC coupled amplifiers

3. Analyze the frequency response of a transformer coupled transistor amplifier.

4. Analyze the frequency response of a DC coupled transistor amplifier.

5. Analyze the frequency response of a cascade amplifier.

6. Describe the use and method of calculating decibles.

7. Analyze amplifiers in terms of general frequency response.

8. Analyze the single stage amplifier in terms of the amplifier's low frequency response.

9. Analyze the single stage amplifier in terms of the amplifier's high frequency response.

10. Analyze the multistage amplifier in terms of its frequency response.

11. Analyze the cascaded FET in terms of its frequency response.

12. Analyze the cascade triode and pentode amplifier in terms of their frequency responses.

II. Content.

1. Characteristics of general cascaded systems.

2. RC coupled transistor amplifiers.
    A. Input impedance.
    B. Output impedane.
    C. Current gain.

3. Transformer-coupled transistor amplifiers.

4. Direct-coupled transistor amplifiers.

5. Cascade amplifier.

6. Darlington compound amplifier.

7. Cascaded triode and pentode amplifiers.

8. The decibels.
   A. Logarithms.
   B. The bel.
   C. The decibels.
   D. Gain calculations.

9. General frequency considerations for amplifiers.
   A. Gain vs. frequency response curves for:
      i. RC-coupled amplifiers.
      ii. Transformer-coupled amplifiers.
      iii. Direct-coupled amplifiers.
   B. Low frequency considerations for single-stage transistor amplifiers.
   C. High frequency considerations for a single-stage transistor amplifier.

10. Multistage frequency effects.

11. Frequency effects of cascaded FET amplifiers.

12. Frequency responses of cascaded triode and pentode amplifiers.

UNIT ELEVEN: FOUR-LAYER PNPN DEVICES AND THE UNIJUNCTION TRANSISTOR

I. Objectives.

Upon mastery of the material presented in this unit, the student will have developed the skills necessary to:

1. Describe the general characteristics of a silicon controlled rectifier (SCR).

2. Describe basic SCR operation and construction.

3. Describe the conditions necessary to turn on or turn off an SCR.

4. Explain the differences between an SCR forward breakover voltage and reverse breakdown voltage.

5. Describe the following SCR characteristics and ratings:
   A. Forward breakover voltage.
   B. Holding current.
   C. Forward and reverse blocking regions.
   D. Reverse breakdown voltage.

6. Identify the gate, cathode, and anode terminals.

7. State three applications of an SCR.

8. Describe the operation of a silicon controlled switch.

9. Describe the operation of a gate turn-off switch.

10. Describe the operation of a light activated SCR.

11. Describe the consstruction and operation of a triac.

12. Describe the conditions necessary to turn on or turn off a bidirectional triode thyristor.

13. State two applications for a bidirectional triode thyristor.

14. Describe the operation of a unijunction transistor (UJT).

15. Describe the conditions required to turn on a UJT.

16. Explain how a UJT exhibits a negative resistance once turned on.

17. Describe two applications of a UJT.

18. Describe the operation of a V-FET.

19. Describe the operation of a photo-transistor.

II. Content.

1. Silicon controlled rectifier (SCR).
    A. Basic operation.
    B. SCR characteristics and ratings.
    C. SCR construction and terminal identification.
    D. SCR applications.

2. Silicon controlled switch (SCS).
    A. Basic operation.
    B. SCS applications.

3. Gate turn-off switch (GTO).
    A. Basic operation.
    B. GTO applications.

4. Light activated SCR (LASCR).
    A. Basic operation.
    B. LASCR applications.

5. Bidirectional triode thyristors.
    A. Basic construction and operation.
    B. Volt-ampere characteristics.
    C. Applications.

6. Unijunction transistors.
    A. Basic construction and operation.
    B. Volt-ampere characteristics.
    C. Applications.
    D. Programmable UJTs.

7. V-FET.

8. Photo-transistors.

III. Laboratory Experiments.

Objectives	Experiment Title	Purpose
1,2,5,6,7	SCR characteristics and applications.	1. To demonstrate the operation and examine the characteristics of an SCR. 2. To demonstrate applications of an SCR.
14,15,16,17	UJT characteristics.	1. To demonstrate the operation and examine the characteristics of a UJT. 2. To demonstrate applications of a UJT.
19	Photo-transistor characteristics.	1. To demonstrate the operation and examine the characteristics of a photo-transistor. 2. To demonstrate applications of a photo-transistor.

UNIT TWELVE: INTEGRATED CIRCUITS

I. Objectives.

Upon mastery of the material presented in this unit, the student will have developed the skills necessary to:

1. Explain the need for integrated circuits (ICs) in electronics.

2. Name five advantages that integrated circuits have over conventional circuits.

3. Name three disadvantages of using integrated circuits, compared to conventional circuits.

4. Explain the differences between monolithic, film type, and hybrid integrated circuits.

5. Discuss the differences between linear and digital ICs.

6. Identify three integrated circuit packages.

7. Explain the differences between small scale, medium scale, and large scale integrated circuits.

II. Content.

1. History of the development of ICs.

2. Description of monolithic ICs.
    A. Circuit elements.
        i. Resistance.
        ii. Capacitor.
        iii. Inductor.
        iv. Transistors.
        v. Diodes.
    B. Masks.
    C. The NAND gate IC construction.
        i. P-type silicon water preparation.
        ii. N-type epitaxial region.
        iii. Silicon oxidation.
        iv. Photo lithographic process.
        v. Isolation diffusion.
        vi. Base and emitter diffusion processes.
        vii. Preohmic etch.
        viii. Metalization.
        ix. Packaging.
        x. Testing.
    D. Thick and thin film integrated circuits.
    E. SSI, MSI, and LSI circuits.

UNIT THIRTEEN: OPERATIONAL AMPLIFIERS (OP-AMP)

I. Objectives.

Upon mastery of the material presented in this unit, the student will have developed the skills necessary to:

1. Measure and compute common operational amplifier parameters.

2. Define the following terms and concepts:
    Input offset current
    Input offset voltage
    Input offset resistance
    Input voltage range
    Gain bandwidth product
    Common mode rejection ratio
    Channel separation
    Closed-loop gain
    Inverting input
    Loop gain
    Noninverting input
    Open-loop gain
    Operational amplifier
    Output resistance
    Output voltage swing
    Slew rate

3. Interpret a typical OP-AMP data sheet.

4. Design and predict the performance of basic OP-AMP linear amplifier circuits.

5. Design and predict the performance of basic integrator and differentiator circuits.

6. Design and predict the performance of constant current sources, current-to-voltage converters, and voltage-to-current converters.

7. Design and predict the performance of OP-AMP nonlinear signal processing circuits.

8. Design and predict the operation of OP-AMP generators.

II. Content.

1. Characteristics of the ideal operational amplifier.

2. Schematic symbol for the OP-AMP.

3. Power supply requirements.

4. Interpreting the OP-AMP data sheet.

5. Maximum ratings.
   A. Supply voltage.
   B. Internal power dissipation.
   C. Differential input voltage.
   D. Input voltage.
   E. Operating temperature.
   F. Output short circuit duration.

6. Electrical characteristics.
   A. Input parameters.
   B. Ouput parameters.
   C. Dynamic parameters.
   D. Supply current.
   E. Common mode rejection ratio.
   F. Channel separation.

7. Gain and frequency response.

8. Gain-bandwidth product.

9. Characteristics of the noninverting amplifier.

10. Characteristics of the inverting amplifier.

11. Characteristics of the voltage follower.

12. Characteristics of the summing amplifier.

13. Characterisitcs of the difference amplifier.

14. Design of basic OP-AMP linear amplifiers.
15. Characteristics of the differentiator.
16. Characteristics of the integrator.
17. Design of the basic differentiator and integrator circuit.
18. Characteristics of the constant current source.
19. Characteristics of the current-to-voltage converter.
20. Characteristics of the voltage-to-current converter.
21. Design of basic voltage and current circuits.
22. Characteristics of the comparitor.
23. Design of a comparitor.
24. Characteristics of the Wein-bridge oscillator.
25. Design of a Wein-bridge oscillator.
26. Characteristics of a relaxation oscillator.
27. Design of a relaxation oscillator.

III. Experiments.

Objectives	Experiment Title	Purpose
1,2,3	OP-AMP fundamentals.	1. To measure the input offset voltage of an OP-AMP.
		2. To measure the input bias current of an OP-AMP.
		3. To measure the slew rate of an OP-AMP.
		4. To measure the common mode rejection ratio of an OP-AMP.
		5. To calculate the closed loop response of an OP-AMP by calculating its gain-bandwidth product.
4	Basic OP-AMP linear amplifier circuits.	1. To demonstrate the design and operation of the following: A. Voltage follower. B. Noninverting amplifier. C. Inverting amplifier. D. Two-input summing amplifier. E. Difference amplifier.

5	OP-AMP differentiator and integrator.	1. To demonstrate the design and operation of a differentiator and an integrator.
6	OP-AMP voltage and current circuits.	1. To demonstrate the design and and operation of a constant current source and a current-to-voltage converter.
7	The OP-AMP comparator.	1. To demonstrate the design and operation of a comparator and a comparator used as a sine wave-to-square wave converter.
8	The OP-AMP Wien-bridge sine wave oscillator.	1. To demonstrate the design and operation of a Wein-bridge sine wave oscillator.

UNIT FOURTEEN: OSCILLATOR CIRCUITS

I. Objectives.

Upon mastery of the material presented in this unit, the student will have developed the skills necessary to:

1. Describe the basic concepts of feedback.

2. List the improvements in circuit operation obtainined from using voltage feedback.

3. Discuss the different types of feedback circuits.

4. Discuss feedback amplifier stability.

5. Discuss how an oscillator uses feedback.

6. Describe the operation of a phase shift oscillator.

7. Describe the operation of an LC-tuned oscillator circuit.

8. Describe the operation of a Colpitts oscillator circuit.

9. Describe the operation of a Hartley oscillatory circuit.

10. Describe the operation of a crystal oscillator circuit.

11. Describe the operation of an OP-AMP amplifier circuit.

II. Content.

1. Feedback concepts.
   - A. Voltage feedback connection.
   - B. Voltage gain with feedback.

2. Types of feedback circuits.
   - A. Voltage-series feedback amplifier.
   - B. Voltage-shunt feedback amplifier.
   - C. Current-series feedback amplifier.
   - D. Current-shunt feedback amplifier.

3. Practical voltage-series negative feedback amplifier circuits.
   - A. Transistor.
   - B. FET.
   - C. Two-stage voltage-series feedback.
   - D. Current-series feedback amplifier.

4. Feedback amplifier stability.
   - A. Phase and frequency considerations.
   - B. Nyquist criterion.
   - C. Gain and phase margins.

5. Operation of a feedback circuit as an oscillator.

6. Phase shift oscillator.
   - A. Operation of an idealized phase shift oscillator.
   - B. FET phase shift oscillator.
   - C. Transistor phase shift oscillator.

7. The LC tuned oscillator circuit.
   - A. The tuned-drain FET oscillator circuit.
   - B. Bipolar transistor LC oscillator circuit.
   - C. Tuned-input, tuned-output oscillator circuits.

8. Colpitts oscillator.
   - A. The FET Colpitts oscillator.
   - B. The transistor Colpitts oscillator.

9. Hartley oscillator.
   - A. FET oscillator.

10. Crystal oscillator.
    - A. Characteristics of a quartz crystal.
    - B. Series resonant circuits.
    - C. Parallel resonant circuits.

11. OP-AMP oscillator circuits.
    - A. Phase shift oscillator.
    - B. Colpitts oscillator.
    - C. Crystal oscillator.
    - D. Wein-bridge oscillator.

12. Unijunction oscillator.

III. Laboratory Experiments.

Objectives	Experiment Title	Purpose
5	Characteristics of a practical tank circuit.	1. To construct an LC tank circuit and observe its characteristics. 2. To observe damped oscillation and the sine wave output of the tank circuit.
7,8,9	LC oscillator circuits.	1. To construct a Colpitts oscillator and observe how changing frequency-determining components affects the circuit output. 2. To construct a Hartley oscillator and observe how changing frequency-determining components affects the circuit output.
10	Crystal oscillator.	1. To construct a Colpitts oscillator and observe how placing a crystal in the feedback path increases oscillatory stability. 2. To construct a Pierce crystal oscillator and observe its operation on its fundamental and second harmonic frequencies.
11	OP-AMP generators.	1. To demonstrate the design and operation of the following: A. Wein-bridge sine wave oscillator. B. Relaxation oscillator. C. Combination square and triangle wave oscillator.

UNIT FIFTEEN: DC POWER SUPPLIES

I. Objectives.

Upon mastery of the material presented in this unit, the student will have developed the skills necessary to:

1. Discuss the operation of a diode used as a rectifier.

2. Discuss the operation of half-wave rectification.

3. Calculate the average DC ouput voltage of a half-wave rectifier.

4. Discuss the operation of circuits that provide full-wave rectification.

5. Calculate the average DC output voltage of a full-wave rectifier.

6. Discuss the characteristics of filter circuits.

7. Define and calculate the following:
    A. Ripple factor.
    B. % ripple.
    C. Voltage regulation.
    D. % voltage regulation.

8. Discuss the operation of a capacitor filter, RC filter, pi-type filter, and L-type filter.

9. Calculate the DC voltage, the RMS value of the AC component of ripple voltage, and ripple factor for each of the filters listed in objective 8.

10. Discuss the effect of the filter on peak diode current.

11. Discuss the operation of voltage multiplying circuits.

12. Discuss the operation of zener and thermistor voltage regulators.

13. Discuss the operation of a transistor voltage regulator.

14. Discuss the operation of a transistor current regulator.

15. Discuss the operation of a complete power supply.

16. Trouble shoot a power supply.

II. Content.

1. Diode rectification.
    A. Half-wave average DC voltage.
    B. Half-wave peak inverse voltage.

2. Full-wave rectification.
    A. Center-taped transformer, full-wave rectifier.
    B. Bridge rectifier circuit.

3. Filter considerations.
    A. Filter voltage regulation.
    B. Ripple voltage.

4. Simple capacitor filter.
    A. Ripple voltage.
    B. DC voltage.
    C. Filter capacitor ripple.
    D. Capacitor filter circuit design.
    E. Diode conduction period.
    F. Peak diode current.

5. RC filter.
    A. DC operation of RC filter section.
    B. AC operation of RC filter section.
    C. Ripple factor and percent ripple with an RC filter section.
    D. Voltage regulation for an RC filter section.

6. Pi-type filter.
    A. DC calculations.
    B. AC calculations.

7. L-type filter.
    A. DC calculations.
    B. AC calculations.

8. Voltage multiplier circuits.
    A. Voltage doubler circuit.
    B. Voltage tripler circuit.
    C. Voltage quadrupler circuit.

9. Regulators.
    A. Definition of regulation.
    B. Zener and thermistor voltage regulators.
    C. Transistor voltage regulators.
    D. Current regulation.

10. Complete power supplies.
    A. Analysis of operation.
    B. Trouble shooting.

III. Laboratory Experiments.

Objectives	Experiment Title	Purpose
7,8,9,16	Unregulated power supplies.	1. To measure the characteristics of half-wave, full-wave, and bridge rectifiers. 2. To observe how the size of filter components affects the ripple amplitude and output voltage. 3. To demonstrate the operation of a voltage doubler.

		4. To trouble shoot an unregulated DC power supply.
13,16	Voltage regulated power supplies.	1. To investigate the operation and characteristics of a shunt regulator.
		2. To investigate the operation and characteristics of a series regulator.
		3. To trouble shoot a voltage regulator circuit.
15,16	DC power supplies.	1. To investigate the operation of representative power supplies.
		2. To trouble shoot representative power supplies.

DIGITAL ELECTRONICS

Introduction

The application of digital electronics is one of the most rapidly expanding technologies. Applications of digital techniques in industrial and commercial activities have produced avenues for new product development in virtually all fields. The adaptation of products such as personal computers, robots, digital watches, and automated supermarket check-outs are widespread phenomena. The advent of the integrated circuit has enabled an exponential proliferation of new digital products.

An electronics technician must have a thorough knowledge of digital theory and extensive practical experience in order to successfully secure entry-level employment. To meet these conditions, extensive laboratory experience is recommended for this course.

Course Objectives

This course will provide the student with the skills necessary to:

1. Discuss the advantages of using digital techniques in electronics equipment.

2. State the applications of digital electronics.

3. Convert binary number systems to decimal number systems and vice versa, and recognize the most common binary codes.

4. Describe the characteristics and operation of the AND, NAND, OR, NOR, and Inverter gaates.

5. State the electrical characteristics of the RTL, DTL, TTL, ECL, and MOS families of logic circuits.

6. Use Boolean algebra to reduce logic equations developed in the process of designing digital circuits.

7. Describe the operation and applications of flip-flops.

8. Describe the operation and applications of sequential logic circuits such as clocks, counters, and shift registers.

9. Describe the operation of the following combinational logic circuits:

   A. Decoder.
   B. Encoder.
   C. Multiplexers.
   D. Exclusive OR Gate.
   E. Code converters.
   F. Read-only memories.
   G. Programmable logic arrays.

10. Develop a technique for design of sequential and combinational logic circuits.

11. Explain the operation of digital VOMs and counters.

12. Describe the operation of digital computers to the functional block diagram level.

Course Content

UNIT ONE: INTRODUCTION

I. Objectives.

This unit will provide the student with the skills necessary to:

1. List five examples of electronics equipment that use digital techniques.

2. List the advantages of digital techniques over analog methods.

3. Given a list of electronic components, physical variables, and devices, categorize them as digital or analog.

4. Provide a short overview of the history and development of computing devices.

5. State the characteristics of modern computers.

6. State the characteristics of analog computers.

7. State the characteristics of digital computers.

8. Describe the functioning of computers in general terms.

9. Describe examples of computer applications in four different industries.

II. Content.

1. A short history of the development of computing devices from the intoduction of the abacus by the Chinese and Greeks (2000 BC) to the development of large scale integrated circuits (1960's).

2. Characteristics of analog computers.

3. Characteristics of digital computers.

4. Computer applications.

III. Laboratory Experiments.

There are no recommended experiments for this unit. A demonstration of the operation of a micro or mini computer would be appropropriate.

Unit Two: Number Systems and Codes

I. Objectives.

This unit will provide the student with the skills necessary to:

1. Discuss the characteristics of the decimal counting system which will include the concept of a place value system, and define the concepts of "least significant digit" and "most significant digit".

2. Discuss the characteristics of the octal, hexadecimal, and binary numbering systems.

3. Given an octal number, convert it to a number in decimal, hexadecimal, and binary equivalents.

4. Given a hexadecimal number, convert it to its decimal, octal, and binary equivalents.

5. Convert a decimal number to its octal, hexadecimal, and binary equivalents.

6. Convert a binary number to its octal, hexadecimal, and decimal equivalents.

7. Convert a binary-coded decimal number to its binary and decimal equivalents.

8. Convert a decimal number to its binary-coded decimal equivalent.

9. Covert a decimal number to its binary-coded equivalent.

10. State the characteristics of the following alphanumeric codes and their applications:

    A. Binary Coded Decimal Interchange Code (BCDIC).
    B. Extended Binary Coded Decimal Interchannge Code.
    C. American Standard Code for Information Interchange (ASCII).

11. State the characteristics of the Gray, BCD, and excess 3 digital codes.

12. State the two ways in which binary data are represented with digital hardware.

13. State the advantages and disadvantages of serial and parallel methods of data transmission.

14. Explain the use of parity checking to determine if the transmitted data have been altered during transmission.

15. Define the term "computer word".

II. Content.

1. Characteristics of numbering systems.
    A. Base.
    B. Least significant character.
    C. Most significant character.
    D. Place value system.
    E. Method of converting from one numbering system to another.

2. Characteristics of the binary number system.

3. Characteristics of the octal numbering system.

4. Characteristics of the decimal numbering system.

5. Charactrisitcs of the hexadecimal numbering system.

6. Characteristics of the binary coded decimal system.

7. Alphanumeric codes.
    A. BCD Interchange Code.
    B. Extended BCD Interchange Code.
    C. American Standard Code for Information Interchange.

8. Digital codes.
    A. Gray Code.
    B. Excess 3 Code.

9. Parity checking.

10. Serial and parallel data transmission.

11. Computer words.

12. Binary data representation with digital hardware.

III. Laboratory Experiments.

Objectives	Experiment Title	Purpose
3,4,5,6,7,8,9	Numbering systems.	1. To gain skill in converting numbers from one numbering system to another.

UNIT THREE: BINARY ARITHMETIC

I. Objectives.

This unit will provide the student with the skills necessary to:

1. Add numbers in the binary number system.
2. Subtract numbers in the binary number system.
3. Represent signed numbers in the binary number system.

II. Content.

1. Addition and subtraction in various number systems.
2. Addition and subtraction of binary numbers.
3. Adding and subtracting signed binary numbers.
4. Two's complement arithmetic.

III. Laboratory Experiments.

There are no experiments recommended for this unit.

UNIT FOUR: LOGIC FUNCTIONS AND DIAGRAMS: BOOLEAN ALGEBRA

I. Objectives.

This unit will povide the student with the skills necessary to:

1. Describe the characteristics of a logic variable.
2. State the three basic logic operations.
3. Describe the AND logic function by:
    A. Showing how it is symbolized.
    B. Drawing its logic symbol.
    C. Writing out the truth table for the logic function.

4. Describe the OR logic function by:
   - A. Showing how it is symbolized.
   - B. Drawing its logic symbol.
   - C. Writing out the truth table for the logic function.

5. Describe the NOT logic function by:
   - A. Showing how it is symbolized.
   - B. Drawing its logic symbol.
   - C. Writing out the truth table for the logic function.

6. Write a Boolean expression for a given logic diagram.

7. Draw a logic diagram from a given Boolean expression.

8. Describe the Exclusive-OR function by:
   - A. Showing how it is symbolized.
   - B. Drawing its logic symbol.
   - C. Writing out the truth table for this logic function.

9. State the postulates, algebraic properties, and theorems (DeMorgan and the Absorption Theorems) for Boolean Algebra.

10. Given a Boolean expression, simplify it and show by use of truth tables the equivalency of the two statements.

11. Given a Boolean expression, simplify it using Boolean theorems and show the equivalency of the two statements by use of truth tables.

12. Discuss the use of a Karnaugh Map to visualize and simplify Boolean expression.

14. Given a Boolean Expression, simplify it by usng a Karnaugh map and verify the result of the process with a truth table.

II. Content.

1. Description of first-level logic diagrams.

2. Description of second-level or implementation logic diagrams.

3. Brief outline of the deveolopment of Boolean Algebra.

4. Logic variables.
   - A. Definition of a variable.
   - B. Two-state variables.
   - C. Switch representation of logic variables.

5. Logic operations.
   - A. The conjunction (logical product).
   - B. The disjunction (logical sum).
   - C. The negation.

6. The AND function.
    A. Logic symbol.
    B. Logic diagram symbol.
    C. Truth table.
    D. Switching circuit implementation.

7. The OR function.
    A. Logic symbol.
    B. Logic diagram symbol.
    C. Truth table.
    D. Switching circuit implementation.

8. The NOT function.
    A. Logic symbol.
    B. Logic diagram symbol.
    C. Truth table.
    D. Switching circuit implementation.

9. Boolean expressions.
    A. Converting verbal expressions to logic statements.
    B. Converting logic statements to logic diagrams.

10. The Exclusive-OR function.
    A. Logic symbol.
    B. Logic diagram symbol.
    C. Truth table.
    D. Switching circuit implementation.

11. Boolean postulates and theorems.
    A. Postulates.
    B. Algebraic properties.
    C. Theorems.
    D. DeMorgan's Theorem.
    E. Absorption Theorem.

12. Truth tables.

13. Simplification of logic expressions using Boolean postulates and theorems.

14. Karnaugh maps.
    A. Description of a Karnaugh map.
    B. Rules for a two-variable Karnaugh map.
    C. Rules for a three-variable Karnaugh map.
    D. Rules for a four-variable Karnaugh map.

III. Laboratory Experiments.

Objectives	Experiment Title	Purpose
3,4,5	Characteristics of logic function.	1. To become familiar with the AND, OR, and inversion logic functions.

		2. To implement the basic logic functions with a simple switching system.
		3. To make a truth table for each of the circuits in purpose 2.
9,10,11,12 13,14	Simplification of logic expressions.	1. To develop skills in expressing written statements as Boolean expressions.
		2. To develop skills in reducing Boolean expressions to their simplist forms.
		3. To verify the equivalence of Boolean statements.
		4. To implement the stated problem with simple switching circuits.

UNIT FIVE: SEMICONDUCTOR DEVICES AND THEIR APPLICATIONS IN DIGITAL CIRCUITS

I. Objectives.

This unit will provide the student with the skills necessary to:

1. Name the two types of semiconductor materials, their atomic structures, and their electrical characteristics.

2. Explain the operation of a diode.

3. Explain the operation of a bipolar transistor.

4. Explain the operation of MOSFETs.

5. Draw the schematic diagram representations of NPM and PMP bipolar transistors and all types of MOSFETs.

6. Draw a diagram of a properly biased bipolar transistor.

7. Explain the three operating modes of a bipolar transistor.

8. Design and construct a bipolar transistor switching circuit.

9. Discuss the operation of a diode-resistor AND gate.

10. Discuss the operation of a diode-resistor OR gate.

11. Design, construct, and evaluate a transistor logic level inverter.

12. Discuss the operation of typical TTL (transistor-transistor logic) inverter circuit.

II. Content.

1. Semi-conducting materials.
    - A. Structure and characteristics of S_i and G_e.
    - B. P-type materials.
    - C. M-type materials.

2. The diode as a unilateral conductor.

3. The diode-resistor OR gate.

4. The diode-resistor AND gate.

5. Review of basic transistor operation.

6. The bipolar transistor switch.
    - A. Modes of operation.
        - i. Saturation characteristics.
        - ii. Shut-off characteristics.
    - B. Saturated switching circuits.
    - C. Switching speed.
    - D. Non-saturated switching circuits.

7. The transistor as a logic level inverter.

8. The transistor in totem-pole connection.

9. MOS field effect transistors.
    - A. N-channel MOSFET.
    - B. P-channel MOSFET.
    - C. Bipolar transistor characteristics relative to MOSFET.
    - D. MOSFET circuits.

III. Laboratory Experiments.

Objectives	Experiment Title	Purpose
9,10	Diode gates.	1. To provide familiarty with the diode-resistor AND and OR gates.
8,11	Bipolar transistor switch.	1. To demonstrate the operation, electrical characteristics, and design of a bipolar transistor switch.
12	Totem-pole circuit.	1. To demonstrate the operation, electrical characteristics, and design of a bipolar transistor switch.
	Complementary CMOS inverter.	1. To demonstrate an inverter circuit that draws minimal current in either output state.

UNIT SIX: BIPOLAR GATES

I. Objectives.

This unit will provide the student with the skills necessary to:

1. Define the term "gate" as used in digital electronics.

2. Design the following categories of switching modes.
   - A. Current sourcing.
   - B. Current sinking.
   - C. Current mode.

3. Discuss the resistor-transistor logic (RTL) family characteristics.

4. Discuss the diode-transistor logic (DTL) family characteristics.

5. Discuss the transistor-transistor logic (TTL) family characteristics.

6. Discuss the emitter-coupled logic (ECL) family characteristics.

7. Interpret the manufacturer's specification sheets for the logic families discussed above.

8. Describe the detailed operation and capabilities of TTL and ECL integrated circuits, given a schematic diagram of the circuit.

II. Content.

1. Definition of a gate.

2. Switching modes.
   - A. Current sourcing
   - B. Current sinking.
   - C. Current mode.

3. RTL family of logic gates.

4. DTL family of logic gates.

5. TTL family of logic gates.

6. ECL family of logic gates.

7. Interpretation of manufacturer's specifications.
    - A. Logic voltage levels.
    - B. Loading rules.
    - C. Wired-OR applications.
    - D. Noise margins.
    - E. Unused inputs.
    - F. Propagation delay.

III. Laboratory Experiments.

Objectives	Experiment Title	Purpose
8	Integrated circuit inverter.	1. To become familiar with the integrated circuit inverter.
8	TTL logic gates.	2. To demonstrate the operation and characteristics of a TTL logic gate and to show how it can be used to perform any of the three basic logic functions.

UNIT SEVEN: MOS LOGIC GATES

I. Objectives.

This unit will provide the student with the skills necessary to:

1. Discuss the advantages of metal oxide semiconductor (MOS) FET devices relative to bipolar transistor devices.

2. Discuss the operation and electrical characteristics of a MOS inverter.

3. Explain the meaning of logic levels.

4. Describe the operation of the NOR and NAND gates constructed from MOSFETs.

5. Describe the characteristics of dynamic logic gates.

6. Describe the characteristics of dynamic MOS gates.

7. Discuss how MOS bipolar interfacing is accomplished.

8. Discuss the term "threshold voltages" in relation to PMOS and NMOS transistors.

9. Discuss the operation of CMOS circuits and their characteristics.

II. Content.

1. Comparison of MOSFET devices and bipolar devices.

2. The operation and characteristics of the basic MOS inverter.

3. Logic level specification.

4. Operation of MOS, NOR, and NAND gates.

5. Characteristics of dynamic logic gates.

6. Characteristics of dynamic MOS gates.

7. MOS/bipolar interface.

8. Threshold voltages.

9. CMOS characteristics.

10. CMOS gate characteristics.

III. Laboratory Experiments.

Objectives	Experiment Title	Purpose
2,3,4	CMOS logic gates.	1. To demonstrate the operation and characteristics of a CMOS logic gate, and to show how it can be used to implement any of the three basic logic functions.

UNIT EIGHT: COMBINATIONS OF GATES FOR LOGIC FUNCTIONS

I. Objectives.

Mastery of the material presented in this unit will provide the student with the skills necessary to:

1. Combine logic gates to perform required logic functions.

2. Design, construct, and evaluate a digital circuit using basic logic gates to solve a given problem.

II. Content.

1. Combinations of AND gates, OR gates, and inverters.

2. Logical circuit combinations with NAND gates and NOR gates.

3. Applications of logic combinations.

III. Laboratory Experiments.

Objectives	Experiment Title	Purpose
1	Combinations of gates.	1. To gain proficiency in tracing through logic circuits containing combinations of gates in order to predict the output for every possible input combination.
1	AND/OR inverter gate.	1. To gain experience in logic circuit tracing. 2. To provide familiarity with the 7450 AND/OR inverter gate and 7404 Hex inverter.
1	Logic circuit implementation with NAND gates.	1. To demonstrate how NAND gates are used to construct AND gates, OR gates and inverters.
1	Logic circuit implementation with NOR gates.	1. To demonstrate the use of NOR gates to construct AND gates, OR gates and inverters.
2	Digital design problem.	1. To gain experience in designing, constructing, and evaluating a logic problem.

UNIT NINE: FLIP FLOPS

I. Objectives.

This unit will provide the student with the skills necessary to:

1. Discuss the applications of flip flops.

2. Write a definition for a flip flop.

3. Identify each of the three types of flip flops from their symbols or logic gate connections.

4. Diagram the symbols and logic gate connections for RS, D, and J-K flip flops.

5. Determine the ouput states for a flip flop, given the input logic levels.

6. Given the input wave forms for an RS, D, or J-K flip flop, draw the corresponding output wave forms.

7. Describe practical applications of flip flops.

8. Write a definition for a register.

9. Determine the binary number stored in a register by measuring the output states.

II. Content.

1. RS flip flop operation.
   A. First-level logic diagram.
   B. Symbol.
   C. Truth table.
   D. Operation.
   E. Implementation of the RS flip flop using NOR gates.
   F. Implementation of the RS flip flop using NAND gates.
   G. Timing charts for an RS flip flop.
   H. Gated RS flip flops using NOR gates.
   I. Gated RS flip flops using NAND gates.
   J. Master-slave RST flip flop.
   K. Direct RST flip flop.

2. D-type flip flops.
   A. First-level logic diagram.
   B. Symbol.
   C. Truth table.
   D. Operation.

3. J-K type flip flop.
   A. First-level logic diagram.
   B. Symbol.
   C. Truth table.
   D. Operation.
   E. Input and output wave forms.
   F. Analysis of the timing pulse for the T input of the J-K flip flop.
   G. Timing charts for DTL, RTL, and TTL J-K flip flops.

4. Applications of flip flops.
   A. Registers.

III. Laboratory Experiments.

Objectives	Experiment Title	Purpose
3,4,5,6	RS flip flops.	1. To construct and evaluate an RS flip flop from discrete components. 2. To construct and evaluate an RS flip flop with IC inverters. 3. To construct and evaluate an RS flip flop with NAND gates.

		4. To construct and evaluate an RS flip flop with NOR gates.
3,4,5,6	D-type flip flops.	1. To demonstrate the operation and characteristics of a J-K flip flop.

UNIT TEN: REGISTERS

I. Objectives.

Mastery of the material presented in this unit will provide the student with the skills necessary to:

1. Write a definition for a register.

2. Describe the differences between parallel and serial or shift registers.

3. Discuss parallel entry of data into a register.

4. Discuss how JAM entry overcomes the need to reset the register before entering new data.

5. Discuss how data can be transferred between registers.

6. Explain the operation of a shift register.

7. List four applications of shift registers.

II. Content.

1. Parallel entry.

2. JAM entry.

3. Transfer function.

4. Shift registers.
    A. Operation.
    B. Bipolar shift registers.

5. Shift register applications.
    A. Serial-to-parallel and parallel-to-series conversion.
    B. Scaling operations.
    C. Ring counters.

6. MOS shift registers.
    A. Dynamic MOS shift registers.
    B. Static MOS shift registers.

III. Laboratory Experiements.

Objectives	Experiment Title	Purpose
2,3,4,6	Shift registers.	1. To demonstrate the operation and characteristics of bipolar integrated circuit shift registers.
		2. To construct and evaluate a shift register made with flip flops.
		3. To provide familiarity with serial in-parallel-out shift registers.
		4. To provide familiarity with parallel in-parallel-out shift registers.
7	Shift register applications.	1. To demonstrate the following applications of integrated circuit shift registers: A. Multiplication and division of binary numbers. B. Recirculate data in the shift register to retain contents. C. Use of shift registers as ring counters. D. Use of shift registers as Johnston counters.

UNIT ELEVEN: ENCODERS, DECODERS, AND CODE CONVERTERS: COMBINATIONAL LOGIC CIRCUITS

I. Objectives.

This unit will provide the student with the skills necessary to:

1. Discuss the operation of a BCD encoder.

2. Write the definition of an encoder.

3. Write the definition of a decoder.

4. Write the output states of a decoder, encoder, multiplexer, and demultiplexer, given the input states.

5. Name three applications for the multiplex circuit.

6. List four commonly used code conversions.

7. Explain the operation of read-only memory (ROM).

8. State the applications of ROM.

9. Define a programmable logic array.

II. Content.

1. Block diagram of data conversion steps from input to output.

2. BCD encoder.
    - A. First-level logic diagram.
    - B. Truth table.
    - C. Operation.

3. Decoders.
    - A. Definition.
    - B. First-level logic diagrams for:
        - i. Two bit decoder.
        - ii. Hexadecimal decoder.
        - iii. BCD decoder.
        - iv. BCD to seven segment decoder.
    - C. Truth tables for the decoders listed above.
    - D. Code converters.

4. Multiplexers.
    - A. Definition.
    - B. First-level logic diagram.
    - C. Truth table.
    - D. Operation.
    - E. Gating.
    - F. Data steering.

5. Multiplexer applications.
    - A. Parallel to serial data conversion.
    - B. Serial binary word generator.
    - C. Boolean function generator.

6. Demultiplexers.
    - A. Definition.
    - B. First-level logic diagram.
    - C. Operation.
    - D. Serial to parallel conversion with a demultiplexer.

7. Exclusive OR applications.
    - A. Binary adder.
    - B. Parity generator/checker.

8. Read-only memories.
    - A. ROM operation.
        - i. Block diagram.
        - ii. Address decoder.
        - iii. Memory storage elements.
        - iv. Output circuits.

B. ROM construction.
i. Diode matrix ROM.
ii. Bipolar ROMs.
iii. MOS ROMs.
IV. MOSFET ROMs.
C. Access time.

9. ROM applications.
A. Random logic.
B. Code conversion.
C. Arithmtic operations.

10. Micro programming.

11. Programmable logic arrays.
A. Definition of a PLA.
B. General logic diagram of a PLA.

III. Laboratory Experiments.

Objectives	Experiment Title	Purpose
1,2	Decimal to BCD encoder.	1. To design a system for encoding decimal numbers into a BCD code.
3,4	Decoders.	1. To demonstrate the operation of a decoder.
4	7-segment decoder driver.	1. To demonstrate the operation of a 7-segment decoder driver and a 7-segment LED decimal display.
4	Muliplexers.	1. To demonstrate the operation and application of digital multiplexers.
	Exclusive OR applications.	1. To demonstrate the application of exclusive OR and exclusive NOR gates.

UNIT TWELVE: COUNTERS

I. Objectives.

This unit will provide the student with the skills necessary to:

1. Write a definition for a digital counter.

2. List four applications of a digital counter.

3. State why a flip flop is used to construct a counter.

4. Describe the operation of a binary ripple-carry counter.

5. Describe the operation of a BCD ripple-carry counter.

6. State the disadvantages of a ripple-carry counter.

7. Explain how the long propagation delay associated with ripple-carry counters is overcome in a synchronous counter.

8. Explain the operation of a synchronous BCD counter.

9. Discuss methods of pre-setting counters.

10. Explain the operation of down and up-down counters.

II. Content.

1. The definition of a digital counter.

2. Applications of digital counters.

3. Binary ripple-carry counters.
    A. First-level logic diagram.
    B. Input and output wave forms.
    C. Operation.

4. BCD ripple-carry counters.
    A. First-level logic diagram.
    B. Input and output wave forms.
    C. Operation.

5. Propogation delay in ripple-carry counters.

6. Synchronous binary counters.
    A. First-level logic diagram.
    B. Operation.

7. Synchronous BCD counters.
    A. First-level logic diagram.
    B. Operation.

8. Methods of pre-setting counters.

9. Operation of down and up-down counters.

III. Laboratory Experiments.

Objectives	Experiment Title	Purpose
	Binary counters.	1. To wire a four bit counter using J-K flip flops and evaluation of its operation.

	2. To wire a four bit binary down counter using J-K flip flops and evaluation of its operation.
	3. To evaluate the operation of a TTL MSI up/down counter.
Modulo N counters.	1. To demonstrate the operation of a Modulo N counter.
Decade counters.	1. To demonstrate the operation of the decade counter.

UNIT THIRTEEN: CLOCKS AND TIMING

I. Objectives.

This unit will provide the student with the skills necessary to:

1. Discuss the importance of the timing and sequence of operations in digital equipment.

2. Explain the purpose of the clock signal and show a method of developing it.

3. Explain the operation of the Astable multivibrator.

4. Explain the operation of a Schmitt NAND gate square wire generator.

5. Explain the operation of CMOS gates in square wave generators.

6. Explain the operation of a discrete component and IC signal squaring circuit.

7. Explain the operation of a 555 IC timer.

8. Define the term "clock cycle".

9. Discuss how multiphase clock pulses can be developed.

10. Discuss how timing is used in a calculator.

11. Discuss methods for modifying the clock cycle.

12. Discuss a method for sequencing operations.

II. Content.

1. Timing considerations.

2. Clock signals.
    A. Clock cycles.
    B. Clock timing charts.

3. Clock circuits.
    A. Astable multivibrator.
        i. Discrte component schematic diagram.
        ii. First-level logic diagram.
        ii. Circuit operation.
    B. Schmitt NAND gate square wave generator.
    C. DMOS gates in square generators.
    D. Signal squaring circuits.
        i. Discrete component squaring circuits.
        ii. IC signal squaring circuit.
    E. 555-type IC timer.

4. Multiphase clock pulses.
    A. Multiphase clock pulse generator.
    B. Applications.

5. Timing in electronic calculators.
    A. Block diagram operation of an electronic calculator.
    B. Clock pulse generator for an electronic calculator.
    C. Timing chart for an electronic calculator.
    D. Read-out.

6. Methods for modifying the clock cycle.

7. Sequencing operations.
    A. Program counter.
    B. First-level logic diagram for a function sequencer.

III. Laboratory Experiments.

Objectives	Experiment Title	Purpose
3	The astable multivibrator.	1. To construct an astable multivibrator, using discrete components, and analyze the operation of the circuit.
7	The 555 general purpose timer.	1. To demonstrate the operation of the 555 timer in the astable and monostable modes.

UNIT FOURTEEN: DIGITAL CIRCUIT DESIGN

I. Objectives.

This unit will provide the student with the skills necessary to:

1. List the criteria for the design of digital circuits.

2. List the design criteria for digital circuits.

3. Develop the specifications for the digital circuit intended to solve a digital design problem.

4. Develop the truth table for a digital design problem.

5. Use a truth table to write a logic equation that expresses the operation of a combinational logic circuit.

6. Use a Karnaugh map to simplify a logic equation.

7. Select electronic components that will implement the design equations.

8. Construct and evaluate the digital circuit designed to implement the logic equation.

9. For LSI, MSI, SSI, ROMs, and PLAs, state the trade-offs influencing circuit selection.

10. Design a combinational logic circuit for a given application.

11. Design counter and controller circuits for implementing sequential logic applications.

II. Content.

1. Design criteria.
    - A. Problem definition.
    - B. Standards for design evaluation.
    - C. Performance.
        - i. Speed.
        - ii. Size.
        - iii. Power consumption.
        - iv. Reliability.
        - v. Accuracy.
    - D. Cost.
    - E. Trade-offs.

2. Combinational logic design.
   - A. Problem definition.
   - B. Truth table development.
   - C. Logic equations.
   - D. Equation simplification.
     - i. Boolean algebra techniques.
     - ii. Karnaugh maps.

3. Choosing the components for implementing the logic equation.
   - A. Benefits and limitations of:
     - i. LSI: large scale integrated circuits.
     - ii. MSI: medium scale integrated circuits.
     - iii. SSI: small scale integrated circuits.
     - iv. ROM: read only memory.
     - v. PLA: programmable logic array.

4. Designing multiple output combinational logic circuits.

5. Design examples.

III. Laboratory Experiments.

Objectives	Experiment Title	Purpose
1,2,3,4,5,6,	Digital design.	1. Given a combinational logic problem, to construct and evaluate a circuit that will solve the problem.

UNIT FIFTEEN: THE MICROPROCESSOR

This section of the curriculum focuses on real microprocessors. Real MPUs used for training purposes should feature two's complement arithmetic as well as control capacity.

Section One: Number Systems and Codes

Upon mastery of the material presented in this section, the student will have developed the skills necessary to:

I. Objectives.

1. Convert any decimal number to its binary, octal, hexadecimal, and BCD equivalents.

2. Convert any binary number to its decimal, octal, hexadecimal, and BCD equivalents.

3. Convert any octal number to its decimal and binary equivalents.

4. Convert any hexadecimal number to its decimal and binary equivalents.

5. Convert any BCD code into its decimal and binary equivalents.

6. Read and identify popular digital codes, including pure binary, natural 8421 BCD, Gray ASCII, and BAUDOT.

7. Convert a letter or number into its ASCII binary code, and vice-versa.

8. Define the following terms and concepts:
   - Radix
   - Integer
   - Decimal
   - Binary
   - Octal
   - BCD
   - Gray Code
   - ASCII
   - BAUDOT
   - Hexadecimal
   - Most Significant Bit (MSB)
   - Least Significant Bit (LSB)
   - Most Significant Digit (MSD)
   - Least Significant Digit (LSD)
   - Bit
   - Parits

II. Content.

1. Decimal number systems.
   A. Positional notation.

2. Binary number systems.
   A. Positional notation.

3. Converting between the binary and decimal number systems.

4. Octal number system.

5. Conversion from decimal to octal.

6. Converting between the octal and binary number systems.

7. Hexadecimal number system.

8. Conversion from decimal to hexadecimal.

9. Conversion between the hexadecimal and binary number systems.

10. Binary codes.
    A. Binary coded decimal.
    B. 8421 BCD code.
    C. Gray code.
    D. ASCII.
    E. BAUDOT.

III. Laboratory Experiments.

Objectives	Experiment Title	Purpose
3,4,5	Introduction to the microprocessor trainer.	1. To gain experience in operating a microprocessor trainer.

2. To gain experience in entering and verifying a program.

3. To practice converting numbers from one base to another.

Section Two: Microcomputer Basics

I. Objectives.

Upon mastery of the material presented in this section, the student will have developed the skills necessary to:

1. Define the following terms and concepts:
    - Microprocessor
    - Output
    - I/O port
    - Stored program concept
    - Byte
    - Operand
    - Read
    - Execute
    - Bus
    - Microcomputer
    - I/O
    - Instruction
    - MPU
    - Memory
    - Write
    - Mnemonic
    - Input
    - I/O device
    - Program
    - word
    - ALU
    - Address
    - RAM fetch
    - Op code

2. Explain the purpose of the following circuits in a typical microprocessor:
    - A. Accumulator.
    - B. Program counter.
    - C. Instruction decoder.
    - D. Controller sequencer.
    - E. Data register.
    - F. Address register.

3. Using a simplified block diagram of a hypothetical microprocessor, trace the data flow that takes place between the various circuits during the execution of a simple program.

4. Describe the computer's execution of the following op codes:
    - A. LDA.
    - B. ADD.
    - C. CLR.
    - D. STA.
    - E. INC.
    - F. DEC.
    - G. HLT.

5. Describe the difference between inherent, immediate, and direct addressing.

6. Describe how the op codes listed in objective 4 are executed by the microprocessor using different addressing techniques.

7. Write simple, straight-line programs that can be executed by the microprocessor trainer.

II. Content.

1. Terms and conventions.
    - A. Stored program concept.
    - B. Computer words.
    - C. Word length.

2. An elementary microcomputer.
    - A. The microprocessor unit (MPU).
    - B. Memory.
    - C. Fetch-execute sequence.
    - D. Sample program.

3. Executing a program.
    - A. The fetch phase.
    - B. The execute phase.
    - C. Fetching the ADD instruction.
    - D. Executing the ADD instruction.
    - E. Fetching and executing the HLT instruction.

4. Addressing modes.
    - A. Inherent or implied addressing.
    - B. Immediate addressing.
    - C. Direct addressing.
    - D. Sample program using direct addressing.
    - E. Executing the sample program.

5. Combining addressing modes.

III. Laboratory Experiments.

Objectives	Experiment Title	Purpose
3,4,5	Straight line programs.	1. To identify and explain the purpose of each of the following (mnemonics) and the addresing modes each can use: LDA, STA, HLT, ADD, IMCA, CLRA, DECA. 2. To enter, verify, and execute the program step-by-step in order to verify the data flow between registers. 3. To examine and change the contents of the accumulator and program counter. 4. To execute a program designed to add two numbers together, using both immediate and direct addressing.

5. To execute a program designed to multiply two numbers together, using both multiple addition and the direct addressing mode.

6. To illustrate the clear, increment. and decrement op codes.

7. To transfer data between two addresses.

8. To illustrate why data are stored in memory addressed outside of the program.

Section Three: Computer Arithmetic

I. Objectives.

Upon mastery of the material presented in this sectiuon, the student will have developed the skills necessary to:

1. Add two binary numbers together.
2. Subtract one binary number from another.
3. Multiply one binary number by another.
4. Divide one binary number by another.
5. Divide the one's complement of a binary number.
6. Divide the two's complement of a binary number.
7. Add binary numbers using two's complement arithmetic.
8. Manipulate binary numbers using the AND operator.
9. Manipulate binary numbers using the OR operator.
10. Manipulate binary numbers using the exclusive OR operator.
11. Logically invert binary numbers.

II. Content.

1. Binary addition.
2. Binary subtraction.
3. Binary multiplication.
4. Binary division.

5. Representing negative numbers.
    - A. Sign and magnitude.
    - B. One's complement.
    - C. Two's complement.

6. Two's complement arithmetic.

7. Ten's complement arithmetic.

8. Arithmetic with signed numbers.

9. Boolean operations.
    - A. AND operation.
    - B. OR operation.
    - C. Exclusive OR operation.

III. Laboratory Experiments.

Objectives	Experiment Title	Purpose
All	Binary logic and arithmetic instructions.	1. To state the purpose of the following op codes: NEG, SUB, AND, OR. 2. To write a program that divides binary numbers by repetitive subtraction. 3. To illustrate how a negative number is represented in a micro computer. 4. To illustrate the application of two's complement arithmetic. 5. To add numbers of opposite signs. 6. To change binary data from one code to another, using OR and AND logic.

Section Four: Introduction to Programming

I. Objectives.

Upon mastery of the material presented in this section, the student will have developed the skills necessary to:

1. Explain the differences between machine language, assembly language, interpretive language, and computer language.

2. Define the following terms and concepts:

Assembler	Compiler	Interpreter	Object program
Source program	Basic	Fortran	COBOL

3. Draw the symbols used in flow charts and explain the purpose of each.

4. Develop flow charts that illustrate step-by-step the procedures for solving problems.

5. Explain the purpose of conditional and unconditional branching.

6. Using the block diagram of a hypothetical microprocessor, trace the data flow during the execution of a branch instruciton.

7. Compute the proper relative address for branching forward or backward from one point to another in a program.

8. Explain the purpose of the carry, negative, zero, and overflow flags, and:
   A. Give an example of a situation that can cause each to be set.
   B. Give an example of a situation that will cause each to clear.
   C. List eight instructions given to test one of these flags.

9. Write programs that can perform the following functions:
   A. Multiply by repeated addition.
   B. Divide by repeated subtraction.
   C. Convert BCD to binary.
   D. Add multiple-precision numbers.
   E. Subtract multiple-precision numbers.
   F. Add BCD numbers.

II. Content.

1. Branching.
   A. Relative addressing.
   B. Executing a branch instruction.
   C. Branching forward.
   D. Branching backward.

2. Conditional branching.
   A. Conditional codes.
      i. Negative (N) register.
      ii. Zero (Z) register.
      iii. Carry (C) register.
      iv. Overflow (V) register.

3. Conditional branching instructions.

4. Algorithms.
    A. Multiplying by repeated addition.
    B. Dividing by repeated subtraction.
    C. Arithmetic shift accumulatory left (ASIA) instruction.
    D. Converting binary to BCD.

5. Additional instructions.
    A. Add with carry (ADC) instruction.
    B. Subtract with carry (SBC) instruction.
    C. Arithmetic shift accumulator left (ASIA) instruction.
    D. Decimal adjust accumulator (DAA) instruction.

III. Laboratory Experiments.

Objectives	Experiment Title	Purpose
5,7,8	Program branching.	1. To examine the conditional code registers and to determine the conditions that set and reset these codes.
		2. To illustrate applications of the BRA and BEQ instructions.
		3. To practice a short-hand method of calculating a relative address.
		4. To demonstrate how an incorrect address can alter a program.
4,9	Programming.	1. To develop a flow chart for each of the programs below.
		2. To write a program designed to add a column of numbers, using the BRA and BEQ instructions.
		3. To write a program designed to divide by repeated subtraction.
		4. To write a program designed to convert BCD numbers to their binary equivalents.

Section Five: Real Microprocessors

I. Objectives.

Upon mastery of the material presented in this section, the student will have developed the skills necessary to:

1. Draw a programming model of a real MPU.

2. Explain the purpose of each block in a simplified block diagram of a real MPU.

3. Explain the operation of the instruction set for a real MPU.

4. Write simple programs that use indexed and extended addressing.

5. Find the op code, number of MPU cycles, number of bytes, and effects on the condition of the code flags of every instruction for a real MPU.

6. Explain the difference between memory stacks and cascade stacks.

7. Write simple programs that can store data in and retrieve data from a stack.

8. Write programs that use the stack and indexing to move a list from one memory location to another.

9. Explain the operations performed by each of the following instructions:
PVLA, PULB, PSHA, PSHB, DES, IMS, LDS, STS, TXS, AMDTSX.

10. Define the following terms and concepts:
Stack   Subroutine   Nested subroutine   Interrupt
Interrupt vector   Interrupt masking

11. Write programs that use subroutines and nested subroutines.

12. Explain the operations performed by each of the following instructions:
JMP USR BSR RTS.

13. Describe how a real MPU performs input and output operations.

14. Draw flow charts depicting the sequence of events that occur during the following procedures:
A. Reset.
B. Non-maskable interrupt.
C. Interrupt request.
D. Software interrupt.
E. Return from interrupt.
F. Wait for interrupt.

15. Explain the operations performed by each of the following instructions:
WAI SWI RTI SEI CLI

II. Content.

1. Architecture of a real MPU.

2. Programming model of a real MPU.
    - A. Accumulators.
    - B. 16-bit program counter.
    - C. Conditional code registers.
    - D. Index register.
    - E. Stack pointer.

3. Block diagram of a real MPU.

4. Instruction set of a real MPU.
    - A. Arithmetic instructions.
    - B. Data handling instructions.
    - C. Logic instructions.
    - D. Data test instructions.
    - E. Index register and stack point instructions.
    - F. Branch instructions.
    - G. Conditional code register instructions.

5. Addressing modes.
    - A. Extended addressing.
    - B. Indexed addressing.

6. Stack operations.
    - A. Cascade stack.
        - i. Pull instruction.
    - B. Memory stack.
        - i. Stack pointer.
        - ii. Push instruction.
        - iii. Pol A and Pol B instructions.
        - iv. Using the stack.

7. Subroutines.
    - A. Jump (JMP) instruction.
    - B. JSR and RTS instructions.

8. Nested subroutines.

9. Branch to subroutine (BSR) instruction.

10. Input-output (I/O) operations.
    - A. Output operations.
    - B. Input operations.
    - C. Input-output operations.
    - D. Program control of I/O operations.
    - E. Interrupt control of I/O operations.

11. Interrupts.
    - A. Reset.
    - B. Non-maskable interrupts.
    - C. Return from interrupt (RII) instructions.
    - D. Interrupt request (IRQ).
    - E. Interrupt mask instructions.
    - F. Software interrupt (SWI) instructions.
    - G. Wait for interrupt (WAI) instructions.

III. Laboratory Experiments.

Objectives	Experiment Title	Purpose
7,8,9,10, 11	Instruction set for a real microprocessor.	1. To describe and practice developing programs a real micrroprocessor. 2. To write a multi-precision subtraction program. 3. To write a multiplication program designed to multiply any 4-bit binary number times 16_{10}. 4. To verify the operation of a BCD packing program.
4	The indexed addressing mode.	1. To gain experience in using the instruction set of an MPU. 2. To demonstrate the indexed addressing mode.

Section Six: Interfacing

I. Objectives.

Upon mastery of the material presented in this section, the student will have developed the skills necessary to:

1. Define the term "interfacing".

2. Define the following terms and concepts:
   Synchronous I/O device CPU Memory.

3. Define the term "device select pulse".

4. List four different uses for a device select pulse.

5. Define three-state logic and explain the need for it.

6. Define the term "bus" and the verb "to bus".

7. Describe the characteristics of a tri-state, or three-state, buffer, including the data requirements and enable/disable inputs as well as the three-state ouput.

8. Write a truth table for a three-state device.

9. Describe the characteristics of three-state IC's (e.g. the 74125, 74126, and 8095).

10. Write a truth table of a three-state latch/buffer.

11. Explain the purpose of each of the control lines of a real MPU.

12. Explain the timing relationships between clock signals and the information on the address, data, and R/W lines of the MPU.

13. Identify several different arrangements used in static RAMs.

14. Draw the logic diagram of a simple address decoder.

15. Explain the operation of a static RAM storage cell.

16. Show four different methods by which an MPU can drive seven segment displays.

17. Draw a diagram showing how mechanical switches can be connected to the MPU.

18. Explain how the MPU can eliminate the effects of a contact bounce.

19. Explain the operation of a program that detects contact closure of switches, provides for debouncing, and decodes a simple keyboard.

20. Draw a simplified block diagram of a PIA and explain the purpose of the output control and data direction registers.

21. Write a simple program that will configure the PIA in any desired input-output combination.

22. Explain how the PIA can be used to drive displays and encode keyboards.

II. Content.

1. Interfacing fundamentals.
    A. Buses.
    B. 3-state logic.

2. MPU interface lines.
    A. Instruction timing.
    B. Timing of program segments.
    C. The data sheet.

3. Interfacing with random access memory.
    A. Static RAM storage cell.
        i. Write operation.
        ii. Read operation.
    B. 128-word by 8-bit RAM.
    C. 256-word by 4-bit RAM.
    D. Connecting RAM to MPU.
    E. Address decoding.

4. Interfacing with displays.
    - A. The 7-segment display.
    - B. Driving the 7-segment display.
    - C. Using an addressable latch.
    - D. Multiplexing displays.

5. Interfacing with switches.
    - A. Interfacing requirements.
        - i. Switch selection.
        - ii. Detecting contact closure.

6. Typical keyboard arrangement.
    - A. Address decoder circuit.
    - B. Detecting and encoding a key enclosure.
    - C. Eliminating contact bounce.

7. The peripheral interface adapter (PIA).
    - A. I/O diagram.
    - B. PIA registers.
    - C. Addresing the PIA registers.
    - D. Initializing the PIA.
    - E. Addressing the PIA.

8. Using the PIA.
    - A. Proving 7-segment displays.
    - B. Decoding keyboards.
    - C. Decoding a switch matrix.

III. Laboratory Experiments.

Objectives	Experiment Title	Purpose
12,13	Memory circuits.	1. To demonstrate how memory circuits can be connected to a microprocessor.
		2. To demonstrate the timing requirements for memory circuits.
		3. To demonstrate how data are stored and read from memory.
		4. To demonstrate a memory test to insure proper, reliable operation.
	Clock.	1. To develop a clock program.
		2. To show how the interrupt request can be implemented.
		3. To show how an external timing signal can synchronize an MPU.

14,15	Address decoding.	1. To show the differences between full and partial address decoding.
		2. To show how an address decoding chart is assembled.
		3. To show how an address can be decoded using various types of logic circuits.
		4. To show how to construct a memory address map.
16,17,18 19	Data output and data input.	1. To interface a microprocessor to an external data display.
		2. To demonstrate how a 7-segment display is interfaced to a microprocessor.
		3. To demonstrate how software can be used to eliminate hardware.
		4. To develop interfacing methods for electromechanical devices.
		5. To demonstrate how to construct a circuit for writing data to a microprocessor.
		6. To program a microprocessor to accept externally supplied data.
		7. To develop a software program for debouncing a switch.
		8. To show how to select a debounce routine to fit a specific system.
20,21	The peripheral interface adapter (PIA).	1. To demonstrate how to interface an MPU to the outside world using a PIA.
		2. To demonstrate how the PIA can be used as an input, output, or I/O device.

3. To demonstrate how a transducer can be interfaced with an MPU.
4. To write an output program that will drive an analog device.
5. To demonstrate parallel-to-serial conversion using a PIA.

ROBOTICS

Introduction

The term "robot" is reportedly derived from the Czech word for worker or serf, "robotnik".[1] The word was popularized as early as 1920. Since any device capable of performing mechanical, routine tasks on command is considered a robot, robotics cannot be considered a "new" technology in the literal sense of the term. However, the industrial use of robots has proliferated only since robot manufacturers have developed the ability to provide mechanical devices that are compact, reliable, and easily programmable. The development of new alloys, miniaturized motors, and the integrated circuit has enabled robot manufacturers to meet these requirements. In particular, the microprocessor and its associated support devices have contributed greatly to the expansion of robotics technology because microprocessors enable robots to be programmed and reprogrammed easily and reliably.

This course is designed to introduce secondary school students to the construction, operation, and application of industrial robots. The scope and depth of the course depends upon the students' background. For students who have completed an electronics technology program that includes digital electronics and microprocessor programming and interfacing, portions of this course will be a review of material covered in previous courses. As a minimum prerequisite, it is assumed that all students enrolling in this course have a general knowledge of basic electricity and mechanics.

COURSE CONTENT

PART ONE: INTRODUCTION

UNIT ONE: INTRODUCTION TO ROBOTICS

I. Objectives.

Upon mastery of the material presented in this unit, the student will have developed the skills necessary to:

1. Define the term "robot" developed by the Robot Institute of America.

2. Name four or five basic components of an industrial robot.

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[1] Ayers and Miller [1983], p. 1.

3. State the reasons for adopting industrial robots.

4. State three industrial applications of robots in situations in which human labor is traditionally employed.

5. State the socio-economic factors that affect the introduction of robots into the workplace.

6. State the criteria that must be met by the industrial robot before it is introduced in the workplace.

7. State the basic limitations that must be considered when deciding whether to implement robots in a production process.

8. Describe the two basic types of industrial robots.

9. Describe the types of motion available to industrial robots.

10. Summarize the function of each of the following subsystems of a robot:
   - A. The gripper.
   - B. Control system.
   - C. Power system.
   - D. Measuring system.
   - E. Sensors.

11. State the three ways in which a robot may be programmed.

12. Describe three different work arrangements for a robot.

13. Summarize the three basic characteristics of an industrial robot.

II. Content.

1. Definition of the term "robot".

2. Basic components of an industrial robot.
   - A. Frame/structure.
   - B. Manipulator.
   - C. Controller.
   - D. Power supply.
   - E. Sensor system.

3. Purposes of robots in industrial applications.
   - A. Safety considerations.
   - B. Effectiveness of human vs robot execution of a task.

4. Basic considerations in implementing robots for specific applications.

5. Types of robots.
   - A. Non-servo.
   - B. Servo controlled.

6. Motion.
   A. Degrees of freedom.
   B. Methods of arm movement.
      i. Hydraulic.
      ii. Pneumatic.
      iii. Mechanical linkages.
      iv. Electric drives.

7. Summary of component functions.
   A. Gripper.
   B. Control system.
   C. Power system.
   D. Measuring system.
   E. Sensors.

8. Methods of programming.

9. The robot in the work place.
   A. Environmental considerations.
   B. Robot set up.

10. Required robot characteristics.
    A. Flexibility.
       i. Handling operations.
       ii. Fabrication operations.
    B. Reliability.
    C. Ease of teaching.

11. Advantages of robot applications.

12. Disadvantages of robot applications.

13. Applications of robots in industry.

III. Laboratory Experiments.

Objectives	Experiment Title	Purpose
5,9,10	Orientation to robots.	1. To identify the 5 major subassemblies of a robot. 2. To determine the degrees of freedom the robot possesses. 3. To determine the type of programming required to operate the robot. 4. To determine how the robot arm is actuated.

UNIT TWO: ROBOTICS FUNDAMENTALS

I. Objectives.

Upon mastery of the material covered in this unit, the student will have developed the skills necessary to:

1. Discuss the differences in the axes of movement in the range of robots which have from two to seven axes.

2. Distinguish the difference between the apparent axis of motion and the axis of the coordinate system used for robot control.

3. Describe the different axial configurations used for industrial robots.

4. Describe the characteristics of the servo controlled mechanical arm, which serves as the robot's manipulator.

5. Describe the characteristics of the power unit that is used to provide the energy to move the manipulator and its load through space.

6. Describe the function of the control unit and the types of robot functions it must control.

7. List the sub-assemblers that constitute the control unit.

8. Describe the characteristics of a servo-control system.

9. Describe three basic approaches to programming a robot.

10. Discuss the characteristics of point-to-point (PTP) controllers.

11. Discuss the characteristics of the continuous path controller.

12. Describe the robot's decision-making processes.

13. List the three categories of sensors that will be available for the robot within the next five years.

14. Discuss the characteristics of the two types of tactile sensors used in industrial robots.

15. Define the term "stability" as it applies to robots.

II. Content.

- 1. Definitions of movement.
  - A. Number of axes of movement (degrees of freedom).
    - i. Axis of rectangular motion.
      - a. Translation.
      - b. Elevation.
      - c. Reach.
    - ii. Axis of rotation.
      - a. Pitch.
      - b. Roll.
      - c. Yaw.
  - B. Reference axes.
    - i. Apparent axis of rotation.
    - ii. Coordinate axes used for robot control.
    - iii. Use of cylindrical or spherical coordinates.
  - C. Axial configurations used for industrial robots.
    - i. All translational system.
      - a. Characteristics.
      - b. Applications.
    - ii. Rotary axis system.
      - a. Characteristics.
      - b. Applications.

- 2. Technology levels.
  - A. Methods of robot classification.
    - i. Servo and non-servo controlled robots.
    - ii. Level of technology classifications.
      - a. Distinction among classifications.
  - B. Characteristics of low technology robots.
  - C. Characteristics of medium technology robots.
  - D. Characteristics of high technology robots.

- 3. General system fundamentals for a five or six axes servo controlled robot.
  - A. Emulation of human functions.
  - B. Characteristics of the manipulator.
    - i. Methods of controlling the mechanical arm.
    - ii. Mechanical assembly of the manipulator.
    - iii. Gripper construction.
    - iv. Position-measuring systems.
    - v. Types of transducers used to measure position.
  - C. Characteristics of the power unit.
    - i. Types.
      - a. Hydraulic.
      - b. Pneumatic.
      - c. Electric.

D. Characteristics of the control unit.
    i. Types of control units in each technology level robot.
    ii. Sub-assemblers in controllers.
    iii. Servo controlled systems.
        a. Components.
        b. Sequence of operations for fluid movement to the actuators.
    iv. General description of the common methods of programming a robot.

E. Control systems.
    i. Point-to-point controllers (PTP).
    ii. Continuous path controllers (CP).
    iii. Controlled path controllers.

F. Decision making in robots.
    i. Definition.
    ii. Purpose.
    iii. Branching.

G. Sensors.
    i. Categories of sensors.
        a. Tactile.
            1. Force sensors.
            2. Geometry/orientation sensors.
        b. Optical.
        c. Voice.

H. Stability.
    i. Definition.
    ii. Design considerations.
    iii. Safety considerations.

III. Laboratory Experiments.

Objectives	Experiment Title	Purpose
5	Robot mechanical assemblies.	1. To identify and demonstrate the operation of the major mechanical assemblies.
6	Robot hydraulic and pneumatic assemblies.	1. To identify and demonstrate the operation of the components make up the hydraulic and pneumatic assemblies.
2,7,8,13	Robot control systems.	1. To identify and demonstrate how the robot is controlled during an activity.

PART II: ROBOT SUBSYSTEMS

Robots are composed of groups of subsystems combined to perform specific functions. These subsystems are usually grouped according to the following categories:

1. The power unit provides the energy to move the manipulator and its load through space. The power system may be integral with the robot or located remotely from the robot. Sensors and interlocks are normally used to insure fail-safe operation.

2. The control unit is the "brain" of the robot. Depending on the technology level of the robot, the controller can be as simple as cam-activated switches for the lowest technology robots or as complicated as separate microprocessors for each of the links of the manipulator. The microprocessor usually requires large memory banks to store the data and programs necessary to control the complex paths the robot follows and the multiple functions it performs.

3. The servo control system provides controlled motion of the end effector anywhere within the robot's limits of movements. The system is usually comprised of three basic components: a servo amplifier used to generate the control signals, the servo valves which control the flow of hydraulic power to the actuators, and the position measuring transducers which provide position feedback data to the servo amplifier.

4. The manipulator, which is a servo-controlled mechanical arm capable of positioning the end effector or gripper anywhere in three-dimensional space within the limits of the working volume.

The power unit will be considered first.

UNIT ONE: ROBOT POWER UNIT SUBASSEMBLY

Introduction

The study of the power unit subassembly for a robot is presented sequentially in terms of energy production, transmission and consumption. The first section studies the AC energy requirements of some representative robots and the end-uses of this energy. The primary end-use consists of driving a pneumatic compressor and/or hydraulic pump that pressurizes the air or fluids used to drive the manipulator. The second section of this unit studies the DC power requirements for a robot and the end-uses of this energy. DC energy is supplied to the control unit, and DC motors are used in positioning the manipulator.

Section One: AC Power: Hydraulic and Pneumatics

I. Objectives.

Upon mastery of the material presented in this section, the student will have developed the skills necessary to:

1. Describe the methods used to generate AC power.

2. List the characteristics of AC generators.

3. State the factors which affect the rating of an AC generator.

4. Describe the characteristics of a revolving armature type generator.

5. Describe the characteristics of a revolving field type generator.

6. Describe the operation of a typical rotating field AC generator.

7. Discuss how single-phase and three-phase generators each produce an AC voltage.

8. Explain how a load is connected to a three-phase, wye-configured AC generator.

9. Explain how a load is connected to a three-phase, delta-configured AC generator.

10. Properly connect a load to both three-phase wye and delta configured AC generator.

11. Discuss the factors that determine when a wye or delta connection is used to attach a load to a generator.

12. Describe how voltage regulation is accomplished in an AC generator.

13. State the advantages and disadvantages of using AC motors.

14. Describe how a rotating magnetic field is produced in a three-phase AC motor.

15. Discuss the operation of an AC induction motor.

16. State Fleming's Rule for AC motors.

17. Discuss the operation of a three-phase synchronous motor.

18. State the advantages of using polyphase AC motors rather than single-phase AC motors in a given industrial application.

19. Describe the operation of a split-phase AC motor.

20. Describe the operation of a single-phase capacitor-start AC motor.

21. Discuss the troubleshooting and repair procedures necessary to maintain AC motors and generators.

22. At the block diagram level, describe the operation of a basic hydraulic system.

23. Describe the structure, operation, and use of a hydraulic system oil reservoir.

24. Discuss the maintenance procedures to be followed for the hydraulic oil reservoir in a hydraulic system.

25. Describe the structure, operation, and applications of the hydraulic vane pump.

26. Discuss the maintenance, troubleshooting, and repair procedures for the hydraulic pump in a hydraulic system.

27. Describe the construction, operation, and uses for the following hydraulic valves:

A. Directional control valves.
    i. One-way valves.
    ii. Gate valves.
    iii. Globe valves.
    iv. Spool valves.
    v. Three-way spool valves.
    vi. Four-way spool valves.
B. Flow control valves.
C. Directional flow valves.

28. Discuss the maintenance, troubleshooting, and repair procedures for control valves in a hydraulic system.

29. Describe the operation, construction, and applications of the most common hydraulic actuators.

30. Discuss the maintenance, troubleshooting, and repair procedures for actuators in a hydraulic system.

31. Describe the similarities and differences between hydraulic and pneumatic systems.

32. Draw a block diagram of a simple pneumatic system and describe the functions of its components.

33. Describe the operation, construction, and application of single and multiple stage air compressors.

34. Discuss the maintenance, troubleshooting, and repair procedures for air compressors in a pneumatic system.

35. Describe the operation, construction, and application of the valves used to control the movement of air in a pneumatic system.

36. Discuss the maintenance, troubleshooting, and repair procedures for the control valves in a pneumatic system.

37. Describe the operation, construction, and application of the most commonly used pneumatic actuators.

38. Discuss the maintenance, troubleshooting, and repair procedures for pneumatic actuators.

II. Content: Section One.

1. AC power generators and distribution systems.
    A. AC generator characteristics.
    B. Types of AC generators.
        i. Revolving armature-type AC generators.
        ii. Revolving field-type AC generators.
    C. Ratings of AC generators.
    D. Operation of a basic AC generator.
        i. Single-phase generators.
        ii. Multiple-phase generators.
    E. Methods of connecting loads to AC power distribution systems.
        i. Wye connection.
        ii. Delta connection.
    F. Voltage regulation in AC generators.

2. AC motors.
    A. Applications for AC motors.
    B. The development of a rotating magnetic field for a three-phase AC generator.
    C. The three-phase AC induction motor.
        i. Fleming's Rule for motors and generators.
        ii. The induction motor stator.
        iii. The induction motor rotor.
        iv. The cage rotor.
        v. The form-wound rotor.
    D. The three-phase synchronous motor.
    E. Single-phase motors.
        i. Split-phase motors.
        ii. Capacitor motors.
    F. Maintenance, trouble shooting, and repair of AC generators and motors.

3. Hydraulic systems.
    A. Block diagram of a basic hydraulic system.
    B. Functional description of the major systems of a simple hydraulic system.
        i. Fluid reservoir.

- ii. Hydraulic pump.
- iii. Control valves.
- iv. Hydraulic motor.

- C. Construction and operation of the oil reservoir.
- D. Maintenance and repair of the oil reservoir.
    - i. Maintaining oil levels.
    - ii. Cleaning and replacement of filters and strainers.
    - iii. Importance of cleanliness in hydraulic circuits.
- E. Construction and operation of hydraulic pumps.
- F. Maintenance and repair of the hydraulic system pump.
- G. Construction and operation of hydraulic valves.
    - i. One-way control valve.
        - a. Ball-type check valve.
        - b. Flapper-type check valve.
    - ii. Two-way control valve.
        - a. Globe valve.
        - b. Gate valve.
        - c. Spool valve.
    - iii. Three-way valve.
    - iv. Four-way valve.
    - v. Flow control valve.
        - a. Meter-in installation.
        - b. Meter-out installation.
    - vi. Pressure control valves.
- H. Maintenance and repair of hydraulic valves.
    - i. Installation and replacement of valves.
    - ii. Rebuilding procedures for valves.
    - iii. Inspection procedures for valves.
- I. Construction and operation of hydraulic actuators.
    - i. Single-acting hydraulic actuators.
    - ii. Double-acting hydraulic actuators.
        - a. Differential-type cylinder.
        - b. Balanced-type cylinder.
    - iii. Rotary actuators.
- J. Maintenance and repair of hydraulic actuators.
    - i. Testing the hydraulic actuator.
    - ii. Rebuilding procedures for hydraulic actuators.

4. Pneumatic systems.
    - A. Block diagrom of a basic pneumatic system.
    - B. Functional description of the major components of a pneumatic system.
        - i. Storage tank, processor and conditioner.
        - ii. Air compressor.
        - iii. Control valve.
        - iv. Actuator.
    - C. Construction of the air storage tank.
    - D. Maintenance and operation of air compressors.
        - i. Filters.
        - ii. Air-water separation unit maintenance.
        - iii. Air pressure relief valve maintenance.
    - E. Construction and operation of air compressors.
        - i. Single-stage units.
        - ii. Multi-stage units.

F. Maintenance, troubleshooting, and repair of air compressors.
   i. Periodic, regular maintenance procedures.
   ii. Procedures for rebuilding or repairing a compressor.
   iii. Determining output pressure.
G. Control valves.
H. Actuators.

III. Laboratory Experiments: Section One.

Objectives	Experiment Title	Purpose
8,9,10,11	Connecting loads to AC power distribution systems.	1. To practice connecting balanced and unbalanced loads to an AC power distribution system.
3,4,5,6,21	AC generators.	1. To become familiar with the construction and assembly of AC generators.
		2. To develop and practice maintenance and repair procedures for AC generators.
17,19,20,21	AC motors.	1. To become familiar with the construction and assembly of AC motors.
		2. To practice connecting AC motors to AC power distribution systems.
		3. To develop and practice maintenance and repair procedures for AC motors.

Section Two: DC Power Sources: DC Motors

I. Objectives.

Upon mastery of the material presented in this section, the student will have developed the skills necessary to:

1. State two practical ways for producing DC power.

2. State the differences between primary cells and secondary cells.

3. Describe the construction and operation of a nickel-cadmium cell.

4. List the characteristics of nickel-cadmium cells.

5. Describe the general characteristics of the rectangular button and cylindrical types of nickel-cadmium cells.

6. Describe the charging characteristics of and charging circuits for nickel-cadmium cells.

7. Write a care and maintenance procedure for nickel-cadmium cells.

8. Describe the construction and operation of a gelled-electrolyte battery.

9. Describe the general characteristics of the gelled-electrolyte cell.

10. Compare the electrical and mechanical characteristics of nickel-cadmium and gelled-electrolyte cells.

11. Describe the charging characteristics of and charging circuits for gelled-electrolyte cells.

12. Choose the appropriate battery for a given application.

13. State the features of a DC motor that make it suitable for robotics applications.

14. Describe the characteristics of a DC motor.

15. Describe the operation of shunt-wound, series-wound, and compound-wound DC motors.

16. State the factors that influence the choice of DC motors for a given application.

17. Discuss the effect of motor load on speed regulation.

18. Describe the operation of DC brushless motors.

19. Describe how the Hall effect is used to control DC brushless motors.

20. Describe the operation of step motors.

21. List the three categories of step motors.

22. Describe the operation of bipolar permanent magnet step motors.

23. Describe the operation of the variable reluctance step motor.

24. Describe the operation of a bifilar step motor.

25. Discuss motor control methods for bipolar and bifilar step motors.

II. Content: Section Two.

1. Batteries -- general information.
    - A. Operation of the simple voltaic cell.
    - B. Electrodes.
    - C. Electrolyte.
    - D. Primary cell.
    - E. Secondary cell.
    - F. Battery.

2. Nickel-cadmium batteries.
    - A. Prominent features.
    - B. Construction.
    - C. Operation of the cell.
    - D. Reversal protection.
    - E. General characteristics.
        - i. Types.
        - ii. Charge retention.
        - iii. Capacity.
        - iv. Discharge rate.
        - v. Charging characteristics.
    - F. Charging techniques.
        - i. Trickle charge.
        - ii. Minimum charge.
        - iii. Standard charge.
        - iv. Quick charge.
        - v. Rapid charge.
        - vi. Charging parameters.
        - vii. Charging circuits.
    - G. Care and maintenance of nickel-cadmium cells.
        - i. Examination of specification sheet.
        - ii. Methods of connecting battery to circuit.
        - iii. Applications.
        - iv. Charging.
        - v. Storage and operating temperatures.
        - vi. Failures.

3. Gelled-electrolyte batteries.
    - A. Construction.
    - B. Battery parameters.
        - i. Operating and storage temperatures.
        - ii. Cell reversal.
        - iii. Battery life.
    - C. Capacity.
    - D. Capacity performance monogram.
    - E. Pulse applications.
    - F. Charging characteristics.
    - G. Charging techniques.
        - i. Charging types.
        - ii. Ideal charger.
        - iii. Constant voltage charger.
        - iv. Float charger.
        - v. Constant current charger.

- H. Charging considerations.
    - i. Initial charging current.
    - ii. Float current.
    - iii. Temperature effects.
- I. General characteristics of gelled-electrolyte batteries.
    - i. Methods of connecting a battery.
    - ii. Charging.
    - iii. Handling.
    - iv. Failures.

4. Comparison of nickel-cadmium and gelled-electrolyte batteries.

5. DC motors.
    - A. Characteristics of DC motors.
        - i. Construction.
        - ii. Torque.
        - iii. Speed regulation.
        - iv. Speed vs. torque.
    - B. Types of DC motors.
        - i. Shunt-wound.
        - ii. Series-wound.
        - iii. Compound-wound.
    - C. Speed control of wound-field DC motors.
        - i. Shunt-field control.
        - ii. Armature-voltage control.
    - D. Motor selection factors.
        - i. Speed range.
        - ii. Speed control under load.
    - E. Reversing DC motors.

6. Brushless DC motors.
    - A. Transistor-switched brushless DC motor operation.
    - B. Hall effect brushless DC motor operation.

7. Step motors.
    - A. Definition of a step motor.
    - B. Step motor types.
        - i. Bipolar permanent magnet step motors.
            - a. Construction.
            - b. Operation.
        - ii. Variable reluctance step motors.
        - iii. Bifilar step motors.
            - a. Construction.
            - b. Operation.
    - C. Step motor control.
        - i. Bipolar control.
        - ii. Unipolar control.

III. Laboratory Experiments: Section Two.

Objectives	Experiment Title	Purpose
14,15,16	DC motors.	1. To identify the components of a DC motor assembly.
		2. To identify the components that have high failure rates.
		3. To perform preventive maintenance on a DC motor.
		4. To troubleshoot a DC motor.
17	DC motor control (manual).	1. To control the speed of a DC motor by varying the voltage to the armature circuit.
		2. To demonstrate the effect of an increase in motor load on the amount of current drawn by the motor.
		3. To illustrate the effect that the amount of voltage applied to the armature has on motor torque.
		4. To observe how the direction of a DC motor can be reversed by changing the polarity of voltage applied to the armature windings.
25	Open loop control of DC step motors.	1. To demonstrate a method of manually single stepping a DC step motor in the open loop control mode.

UNIT TWO: THE MICROPROCESSOR-BASED CONTROL UNIT

Introduction

The microprocessor-based control unit is the brain of the medium and high technology robots. The unit consists of a microprocessor, a memory bank, the interfaces to the position-measuring system, actuator power units, external sensors, and the switches and status indicators necessary to monitor and control the robot. To understand the control unit requires learning microprocessor programming and interfacing. The characteristics of sensing devices and servo controllers must also be studied.

This section of the curriculum focuses on real microprocessors. Real MPUs used for training purposes should feature two's complement arithmetic as well as control capacity.

Section One: Number Systems and Codes

Upon mastery of the material presented in this section, the student will have developed the skills necessary to:

I. Objectives.

1. Convert any decimal number to its binary, octal, hexadecimal, and BCD equivalents.

2. Convert any binary number to its decimal, octal, hexadecimal, and BCD equivalents.

3. Convert any octal number to its decimal and binary equivalents.

4. Convert any hexadecimal number to its decimal and binary equivalents.

5. Convert any BCD code into its decimal and binary equivalents.

6. Read and identify popular digital codes, including pure binary, natural 8421 BCD, Gray ASCII, and BAUDOT.

7. Convert a letter or number into its ASCII binary code, and vice-versa.

8. Define the following terms and concepts:
    - Radix
    - Integer
    - Decimal
    - Binary
    - Octal
    - BCD
    - Gray Code
    - ASCII
    - BAUDOT
    - Hexadecimal
    - Most Significant Bit (MSB)
    - Least Significant Bit (LSB)
    - Most Significant Digit (MSD)
    - Least Significant Digit (LSD)
    - Bit
    - Parits

II. Content.

1. Decimal number systems.
    - A. Positional notation.
2. Binary number systems.
    - A. Positional notation.
3. Converting between the binary and decimal number systems.
4. Octal number system.
5. Conversion from decimal to octal.
6. Converting between the octal and binary number systems.
7. Hexadecimal number system.
8. Conversion from decimal to hexadecimal.
9. Conversion between the hexadecimal and binary number systems.
10. Binary codes.
    - A. Binary coded decimal.
    - B. 8421 BCD code.
    - C. Gray code.
    - D. ASCII.
    - E. BAUDOT.

III. Laboratory Experiments.

Objectives	Experiment Title	Purpose
3,4,5	Introduction to the microprocessor trainer.	1. To gain experience in operating a microprocessor trainer. 2. To gain experience in entering and verifying a program. 3. To practice converting numbers from one base to another.

Section Two: Microcomputer Basics

I. Objectives.

Upon mastery of the material presented in this section, the student will have developed the skills necessary to:

1. Define the following terms and concepts:
    - Microprocessor
    - Output
    - I/O port
    - Stored program concept
    - Byte
    - Operand
    - Read
    - Execute
    - Bus
    - Microcomputer
    - I/O
    - Instruction
    - MPU
    - Memory
    - Write
    - Mnemonic
    - Input
    - I/O device
    - Program
    - word
    - ALU
    - Address
    - RAM fetch
    - Op code

2. Explain the purpose of the following circuits in a typical microprocessor:
    - A. Accumulator.
    - B. Program counter.
    - C. Instruction decoder.
    - D. Controller sequencer.
    - E. Data register.
    - F. Address register.

3. Using a simplified block diagram of a hypothetical microprocessor, trace the data flow that takes place between the various circuits during the execution of a simple program.

4. Describe the computer's execution of the following op codes:
    - A. LDA.
    - B. ADD.
    - C. CLR.
    - D. STA.
    - E. INC.
    - F. DEC.
    - G. HLT.

5. Describe the difference between inherent, immediate, and direct addressing.

6. Describe how the op codes listed in objective 4 are executed by the microprocessor using different addressing techniques.

7. Write simple, straight-line programs that can be executed by the microprocessor trainer.

II. Content.

1. Terms and conventions.
   - A. Stored program concept.
   - B. Computer words.
   - C. Word length.

2. An elementary microcomputer.
   - A. The microprocessor unit (MPU).
   - B. Memory.
   - C. Fetch-execute sequence.
   - D. Sample program.

3. Executing a program.
   - A. The fetch phase.
   - B. The execute phase.
   - C. Fetching the ADD instruction.
   - D. Executing the ADD instruction.
   - E. Fetching and executing the HLT instruction.

4. Addressing modes.
   - A. Inherent or implied addressing.
   - B. Immediate addressing.
   - C. Direct addressing.
   - D. Sample program using direct addressing.
   - E. Executing the sample program.

5. Combining addressing modes.

III. Laboratory Experiments.

Objectives	Experiment Title	Purpose
3,4,5	Straight line programs.	1. To identify and explain the purpose of each of the following (mnemonics) and the addresing modes each can use: LDA, STA, HLT, ADD, IMCA, CLRA, DECA. 2. To enter, verify, and execute the program step-by-step in order to verify the data flow between registers. 3. To examine and change the contents of the accumulator and program counter. 4. To execute a program designed to add two numbers together, using both immediate and direct addressing.

5. To execute a program designed to multiply two numbers together, using both multiple addition and the direct addressing mode.

6. To illustrate the clear, increment, and decrement op codes.

7. To transfer data between two addresses.

8. To illustrate why data are stored in memory addressed outside of the program.

Section Three: Computer Arithmetic

I. Objectives.

Upon mastery of the material presented in this sectiuon, the student will have developed the skills necessary to:

1. Add two binary numbers together.
2. Subtract one binary number from another.
3. Multiply one binary number by another.
4. Divide one binary number by another.
5. Divide the one's complement of a binary number.
6. Divide the two's complement of a binary number.
7. Add binary numbers using two's complement arithmetic.
8. Manipulate binary numbers using the AND operator.
9. Manipulate binary numbers using the OR operator.
10. Manipulate binary numbers using the exclusive OR operator.
11. Logically invert binary numbers.

II. Content.

1. Binary addition.
2. Binary subtraction.
3. Binary multiplication.
4. Binary division.

5. Representing negative numbers.
    A. Sign and magnitude.
    B. One's complement.
    C. Two's complement.

6. Two's complement arithmetic.

7. Ten's complement arithmetic.

8. Arithmetic with signed numbers.

9. Boolean operations.
    A. AND operation.
    B. OR operation.
    C. Exclusive OR operation.

III. Laboratory Experiments.

Objectives	Experiment Title	Purpose
All	Binary logic and arithmetic instructions.	1. To state the purpose of the following op codes: NEG, SUB, AND, OR. 2. To write a program that divides binary numbers by repetitive subtraction. 3. To illustrate how a negative number is represented in a micro computer. 4. To illustrate the application of two's complement arithmetic. 5. To add numbers of opposite signs. 6. To change binary data from one code to another, using OR and AND logic.

Section Four: Introduction to Programming

I. Objectives.

Upon mastery of the material presented in this section, the student will have developed the skills necessary to:

1. Explain the differences between machine language, assembly language, interpretive language, and computer language.

2. Define the following terms and concepts:

Assembler	Compiler	Interpreter	Object program
Source program	Basic	Fortran	COBOL

3. Draw the symbols used in flow charts and explain the purpose of each.

4. Develop flow charts that illustrate step-by-step the procedures for solving problems.

5. Explain the purpose of conditional and unconditional branching.

6. Using the block diagram of a hypothetical microprocessor, trace the data flow during the execution of a branch instruciton.

7. Compute the proper relative address for branching forward or backward from one point to another in a program.

8. Explain the purpose of the carry, negative, zero, and overflow flags, and:
    A. Give an example of a situation that can cause each to be set.
    B. Give an example of a situation that will cause each to clear.
    C. List eight instructions given to test one of these flags.

9. Write programs that can perform the following functions:
    A. Multiply by repeated addition.
    B. Divide by repeated subtraction.
    C. Convert BCD to binary.
    D. Add multiple-precision numbers.
    E. Subtract multiple-precision numbers.
    F. Add BCD numbers.

II. Content.

1. Branching.
    A. Relative addressing.
    B. Executing a branch instruction.
    C. Branching forward.
    D. Branching backward.

2. Conditional branching.
    A. Conditional codes.
        i. Negative (N) register.
        ii. Zero (Z) register.
        iii. Carry (C) register.
        iv. Overflow (V) register.

3. Conditional branching instructions.

4. Algorithms.
    A. Multiplying by repeated addition.
    B. Dividing by repeated subtraction.
    C. Arithmetic shift accumulatory left (ASIA) instruction.
    D. Converting binary to BCD.

5. Additional instructions.
    A. Add with carry (ADC) instruction.
    B. Subtract with carry (SBC) instruction.
    C. Arithmetic shift accumulator left (ASIA) instruction.
    D. Decimal adjust accumulator (DAA) instruction.

III. Laboratory Experiments.

Objectives	Experiment Title	Purpose
5,7,8	Program branching.	1. To examine the conditional code registers and to determine the conditions that set and reset these codes. 2. To illustrate applications of the BRA and BEQ instructions. 3. To practice a short-hand method of calculating a relative address. 4. To demonstrate how an incorrect address can alter a program.
4,9	Programming.	1. To develop a flow chart for each of the programs below. 2. To write a program designed to add a column of numbers, using the BRA and BEQ instructions. 3. To write a program designed to divide by repeated subtraction. 4. To write a program designed to convert BCD numbers to their binary equivalents.

Section Five: Real Microprocessors

I. Objectives.

Upon mastery of the material presented in this section, the student will have developed the skills necessary to:

1. Draw a programming model of a real MPU.

2. Explain the purpose of each block in a simplified block diagram of a real MPU.

3. Explain the operation of the instruction set for a real MPU.

4. Write simple programs that use indexed and extended addressing.

5. Find the op code, number of MPU cycles, number of bytes, and effects on the condition of the code flags of every instruction for a real MPU.

6. Explain the difference between memory stacks and cascade stacks.

7. Write simple programs that can store data in and retrieve data from a stack.

8. Write programs that use the stack and indexing to move a list from one memory location to another.

9. Explain the operations performed by each of the following instructions:
PVLA, PULB, PSHA, PSHB, DES, IMS, LDS, STS, TXS, AMDTSX.

10. Define the following terms and concepts:
Stack Subroutine Nested subroutine Interrupt
Interrupt vector Interrupt masking

11. Write programs that use subroutines and nested subroutines.

12. Explain the operations performed by each of the following instructions:
JMP USR BSR RTS.

13. Describe how a real MPU performs input and output operations.

14. Draw flow charts depicting the sequence of events that occur during the following procedures:
A. Reset.
B. Non-maskable interrupt.
C. Interrupt request.
D. Software interrupt.
E. Return from interrupt.
F. Wait for interrupt.

15. Explain the operations performed by each of the following instructions:
WAI SWI RTI SEI CLI

II. Content.

1. Architecture of a real MPU.

2. Programming model of a real MPU.
A. Accumulators.
B. 16-bit program counter.
C. Conditional code registers.
D. Index register.
E. Stack pointer.

3. Block diagram of a real MPU.

4. Instruction set of a real MPU.
   A. Arithmetic instructions.
   B. Data handling instructions.
   C. Logic instructions.
   D. Data test instructions.
   E. Index register and stack point instructions.
   F. Branch instructions.
   G. Conditional code register instructions.

5. Addressing modes.
   A. Extended addressing.
   B. Indexed addressing.

6. Stack operations.
   A. Cascade stack.
      i. Pull instruction.
   B. Memory stack.
      i. Stack pointer.
      ii. Push instruction.
      iii. Pol A and Pol B instructions.
      iv. Using the stack.

7. Subroutines.
   A. Jump (JMP) instruction.
   B. JSR and RTS instructions.

8. Nested subroutines.

9. Branch to subroutine (BSR) instruction.

10. Input-output (I/O) operations.
   A. Output operations.
   B. Input operations.
   C. Input-output operations.
   D. Program control of I/O operations.
   E. Interrupt control of I/O operations.

11. Interrupts.
   A. Reset.
   B. Non-maskable interrupts.
   C. Return from interrupt (RII) instructions.
   D. Interrupt request (IRQ).
   E. Interrupt mask instructions.
   F. Software interrupt (SWI) instructions.
   G. Wait for interrupt (WAI) instructions.

III. Laboratory Experiments.

Objectives	Experiment Title	Purpose
7,8,9,10, 11	Instruction set for a real microprocessor.	1. To describe and practice developing programs a real microprocessors.

		2. To write a multi-precision subtraction program.
		3. To write a multiplication program designed to multiply any 4-bit binary number times 16_{10}.
		4. To verify the operation of a BCD packing program.
4	The indexed addressing mode.	1. To gain experience in using the instruction set of an MPU.
		2. To demonstrate the indexed addressing mode.

Section Six: Interfacing

I. Objectives.

Upon mastery of the material presented in this section, the student will have developed the skills necessary to:

1. Define the term "interfacing".

2. Define the following terms and concepts:
   Synchronous I/O device CPU Memory.

3. Define the term "device select pulse".

4. List four different uses for a device select pulse.

5. Define three-state logic and explain the need for it.

6. Define the term "bus" and the verb "to bus".

7. Describe the characteristics of a tri-state, or three-state, buffer, including the data requirements and enable/disable inputs as well as the three-state ouput.

8. Write a truth table for a three-state device.

9. Describe the characteristics of three-state IC's (e.g. the 74125, 74126, and 8095).

10. Write a truth table of a three-state latch/buffer.

11. Explain the purpose of each of the control lines of a real MPU.

12. Explain the timing relationships between clock signals and the information on the address, data, and R/W lines of the MPU.

13. Identify several different arrangements used in static RAMs.

14. Draw the logic diagram of a simple address decoder.

15. Explain the operation of a static RAM storage cell.

16. Show four different methods by which an MPU can drive seven segment displays.

17. Draw a diagram showing how mechanical switches can be connected to the MPU.

18. Explain how the MPU can eliminate the effects of a contact bounce.

19. Explain the operation of a program that detects contact closure of switches, provides for debouncing, and decodes a simple keyboard.

20. Draw a simplified block diagram of a PIA and explain the purpose of the output control and data direction registers.

21. Write a simple program that will configure the PIA in any desired input-output combination.

22. Explain how the PIA can be used to drive displays and encode keyboards.

II. Content.

1. Interfacing fundamentals.
    A. Buses.
    B. 3-state logic.

2. MPU interface lines.
    A. Instruction timing.
    B. Timing of program segments.
    C. The data sheet.

3. Interfacing with random access memory.
    A. Static RAM storage cell.
        i. Write operation.
        ii. Read operation.
    B. 128-word by 8-bit RAM.
    C. 256-word by 4-bit RAM.
    D. Connecting RAM to MPU.
    E. Address decoding.

4. Interfacing with displays.
    A. The 7-segment display.
    B. Driving the 7-segment display.
    C. Using an addressable latch.
    D. Multiplexing displays.

5. Interfacing with switches.
    A. Interfacing requirements.
        i. Switch selection.
        ii. Detecting contact closure.

6. Typical keyboard arrangement.
    A. Address decoder circuit.
    B. Detecting and encoding a key enclosure.
    C. Eliminating contact bounce.

7. The peripheral interface adapter (PIA).
    A. I/O diagram.
    B. PIA registers.
    C. Addresing the PIA registers.
    D. Initializing the PIA.
    E. Addressing the PIA.

8. Using the PIA.
    A. Proving 7-segment displays.
    B. Decoding keyboards.
    C. Decoding a switch matrix.

III. Laboratory Experiments.

Objectives	Experiment Title	Purpose
12,13	Memory circuits.	1. To demonstrate how memory circuits can be connected to a microprocessor.
		2. To demonstrate the timing requirements for memory circuits.
		3. To demonstrate how data are stored and read from memory.
		4. To demonstrate a memory test to insure proper, reliable operation.
	Clock.	1. To develop a clock program.
		2. To show how the interrupt request can be implemented.
		3. To show how an external timing signal can synchronize an MPU.
14,15	Address decoding.	1. To show the differences between full and partial address decoding.
		2. To show how an address decoding chart is assembled.
		3. To show how an address can be decoded using various types of logic circuits.
		4. To show how to construct a memory address map.

16,17,18 19	Data output and data input.	1. To interface a microprocessor to an external data display.
		2. To demonstrate how a 7-segment display is interfaced to a microprocessor.
		3. To demonstrate how software can be used to eliminate hardware.
		4. To develop interfacing methods for electromechanical devices.
		5. To demonstrate how to construct a circuit for writing data to a microprocessor.
		6. To program a microprocessor to accept externally supplied data.
		7. To develop a software program for debouncing a switch.
		8. To show how to select a debounce routine to fit a specific system.
20,21	The peripheral interface adapter (PIA).	1. To demonstrate how to interface an MPU to the outside world using a PIA.
		2. To demonstrate how the PIA can be used as an input, output, or I/O device.
		3. To demonstrate how a transducer can be interfaced with an MPU.
		4. To write an output program that will drive an analog device.
		5. To demonstrate parallel-to-serial conversion using a PIA.

UNIT THREE: SENSORS

I. Objectives.

Upon mastery of the material presented in this section, the student will have developed the skills necessary to:

1. Describe the applications for an optoelectronic sensor.

2. List the components of an optical sensing system.

3. Describe the operation and construction of a light-emitting diode and how the semiconductor material used in constructing the device determines the wave length of the emitted light.

4. Describe the operation and construction of a photo-transistor detector.

5. Describe the operation and construction of a photo-Darlington detector.

6. Describe the operation of an optoelectronic sensing system acting as the eyes of a robot.

7. Explain the operation of an interrupter module.

8. Describe how optoelectronic reflector sensor modules can be used to measure the amplitude and frequency of a vibrator.

9. Describe the four major temperature scales.

10. Convert a temperature reading in one scale to any other temperature scale.

11. Describe the operation of bimetallic, resistive, and semiconductor temperature sensing devices.

12. Determine the type of temperature sensor that will provide the greatest accuracy.

13. Describe the applications of temperature sensing for robots.

14. Define the terms "ultrasonics".

15. Describe the applications of ultrasonic sensing systems for a robot.

16. Describe the properties of matter that affect the velocity of longitudinal waves in matter.

17. Describe the term "interface" as it pertains to sound

propagation.

18. Describe the construction and operation of a piezo electric transducer.

19. Describe how an ultrasound thickness measuring system functions.

20. Describe how an ultrasound detection and ranging navigation system operates.

21. Describe the operation of force sensors.

22. Describe the operation of geometry/orientation sensors.

II. Content.

1. Optoelectric sensors.
    - A. Light-emitting diodes.
        - i. LED operation.
        - ii. LED construction.
    - B. Phototransistors.
        - i. Photo-transistor construction.
        - ii. Photo-transistor operation.
        - iii. Photo-Darlington circuits.
    - C. Optoelectronic sensing system operation.
        - i. As a safety device.
        - ii. As a counter.
        - iii. As an interruptor.
        - iv. As an optical tachometer.
        - v. As a vibration sensor.

2. Temperature sensing.
    - A. Temperature scales.
        - i. Scale conversion.
    - B. Temperature sensing devices.
        - i. Bimetallic sensors.
        - ii. Resistive sensors.
            - a. Resistive temperature detector.
            - b. Thin film detectors.
        - iii. Semiconductor sensors.

3. Ultrasound sensors.
    - A. Properties of sound.
        - i. Velocity in solids and liquids.
        - ii. Velocity in gas.
        - iii. How temperature affects velocity.
        - iv. How elasticity affects velocity.
        - v. How density affects velocity.
    - B. Ultrasonic sensing systems.
        - i. Piezo electric transducers.
            - a. Piezo electric effect.
            - b. Piezo electric transducer construction.
            - c. Piezo electric transducer operation.

ii. Ultrasonic thickness measuring system.
    a. Block diagram.
    b. Robot applications.
iii. Ultrasonic detection and navigation systems.
    a. Block diagram.
    b. Robot applications.

4. Tactile sensors.
    A. Force sensing.
        i. Remote sensing of reaction forces.
        ii. Wrist force sensing.
        iii. Work table force sensing.
        iv. Applications of force sensing in robots.
    B. Geometry sensing.
        i. Applications.
            a. Surface defect sensor.
            b. Orientation sensor.

III. Laboratory Experiments.

Objectives	Experiment Title	Purpose
1,2	Optoelectric devices.	1. To measure the electrical charqacteristics of a phototransistor and plate diode.
6,8	Training robot optoelectric sensing system.	1. To become familiar with the optoelectric sensing system for the training robot.
13	Training robot temperature sensing system.	1. To become familiar with the temperature sensing system for the robot.
17,18,19 20	Training robot ultrasound navigation systems.	1. To become familiar with the ultrasound ranging and navigation systems for the robot.
21	Training robot tactile sensing system.	1. To become familiar with the tactile sensing system for the robot.

SERVO-CONTROL SYSTEMS

Introduction

The servo-control system for a robot is used to provide control over the movement of the effector anywhere within the robot's limits of movement. Data collected by the position measuring sub-system of the servo-control system can be used to direct the motion of the end effector through space, thereby eliminating the need for complex programming instructions. Servo-control systems facilitate instructing robots to perform complex paths of motion and sequences of operations.

I. Objectives.

Upon mastery of the material presented in this section, the student will have developed the skills necessary to:

1. Describe the functions performed by the major components of a representative servo-control system.

2. State the purpose of a synchro system.

3. Describe the operation of a synchro system, including:
   - A. Transmitters.
   - B. Receivers.
   - C. Differential transmitters.
   - D. Differential receivers.
   - E. Control transformers.

4. Describe the operation of the following synchro systems:
   - A. Transmitter and receiver synchro system.
   - B. Synchro transmitter-differential transmitter-receiver system.
   - C. Transmitter-differential receiver-transmitter system.
   - D. Synchro transmitter-control transformer system.

5. Determine the amount of voltage induced in various windings of the synchro device, given the applied voltage, motor position, and type of synhro unit.

6. Describe a servo mechanism.

7. Discuss the operation of a basic open loop servo mechanism.

8. Discuss the operation of a basic closed loop servo mechanism.

9. Describe the differences between analog and digital data.

10. Discuss the general principles of digital to analog conversion (DAC).

11. Define the following terms and concepts as applied to a DAC:
    Resolution   Linearity   Accuracy
    Output range   Setting time   Input coding

12. Describe the operation of a binary weighted DAC and methods of interfacing it with an MPU.

13. Describe the operation of 4-bit, 6-bit, and 8-bit DACs.

14. Interface a DAC to an MPU, using a PIA.

15. Discuss the following uses of a DAC:
    - A. As a ramp generator.
    - B. In motor control and positioning.
    - C. As a programmable gain amplifier and attenuator.

16. Explain the purpose and need for analog to digital converters (ADC).

17. List the most common techniques for ADC conversion.

18. List the selection criteria for choice of a conversion process.

19. Describe a sample-and-hold circuit.

20. Describe the following characteristics of a sample-and-hold circuit:

    A. Acquisition time.
    B. Aperature uncertainty time.
    C. Aperature time.
    D. Decay rate.
    E. Feedthrough.

21. Discuss the operation of a servo ADC.

22. Discuss the operation of a successive approximation ADC.

23. Discuss the operation of a dual slope integrator ADC.

24. Interface an ADC to an MPU using a PIA.

II. Contents.

1. Function of the servo-control unit.

2. Basic components of a servo-control system.
    A. Servo amplifier.
    B. Servo controllers.
    C. Position measuring transducers.

3. Synchro and servo mechanisms.
    A. Distinction between sychro and servo mechanisms.
    B. Methods of transferring data.
        i. Mechanical.
        ii. Electrical.

4. Synchro systems.
    A. Characteristics of synchro systems.
    B. Synchro transmitter construction and operation.
    C. Synchro receiver construction and operation.
    D. Differential synchro transmitter construction and operation.
    E. Differential synchro receiver construction and operation.
    F. Control transformer construction and operation.

5. Synchro system operation.
    A. Basic synchro system operation.
    B. Transmitter-receiver synchro system operation.
    C. Synchro transmitter-differential transmitter-receiver system operation.
    D. Transmitter-differential receiver-transmitter system operation.
    E. Synchro transmitter-control transformer operation.

6. Servo mechanisms.
    A. Block diagram of major components and signal flow.
    B. Open loop operation of a servo mechanism.
    C. Closed loop operation of a servo mechanism.

7. Analog-to-digital converters.
    A. General considerations for analog-to-digital signal conversion.
    B. Block diagram of the process of converting analog data to digital data.
    C. Quantizing.
    D. Sample-and-hold circuitry.
    E. A/D conversion circuitry.
        i. Servo converter.
        ii. Dual slope integrator A/D converters.
        iii. Successive approximation A/D converters.
        iv. Parallel conversion.
    F. Selection criteria for A/D converter.
        i. Range.
        ii. Resolution.
        iii. Linearity.
        iv. Monotonicity.
        v. Missing codes.
        vi. Relative accuracy.
        vii. Absolute accuracy.
        viii. Offset error.

8. Digital-to-analog converters.
    A. General considerations for digital-to-analog signal conversion.
    B. Block diagram of the process of converting digital data to analog data.
    C. Features of digital to analog conversion.
        i. Resolution.
        ii. Accuracy.
        iii. Setting time.
        iv. Linearity.
        v. Output range.
        vi. Input coding.
    D. D/A conversion circuitry.
        i. Weighted-current-source D/A conversion method.
        ii. R-2R network D/A conversion method.

III. Laboratory Experiments.

Objectives	Experiment Title	Purpose
7	DC step motor control.	1. To demonstrate a method of manually single stepping a DC step motor in the open loop contol mode.
2,3,4,5	Synchro receivers and transmitters.	1. To investigate the operation of a synchro transmitter and receiver.
		2. To determine the magnitude of the induced voltages, given the applied voltage rotor monitor and type of unit.
8	Servo mechanisms.	1. To familiarize the student with the servo mechanisms used in educational and industrial robotic positioning systems.
10,11,12,13 14,15	Interfacing.	1. To determine the method used to interface the servo-control system to the microprocessor.
		2. To interface the following transducers to the MPU, using an A/D converter: A. Motion sensing transducers. i. Electromechanical switch type. ii. Magnetic induction type. iii. Hall-effect type. iv. Optical transducers. B. Pressure sensing transducers. i. Capacitance transducers. ii. Piezo electric transducers. C. Flow rate transducers. D. Optical transducers.
		3. To produce an analog control voltage, using a D/A converter.
14,24	Digital-to-analog conversion and analog-to-digital conversion.	1. To demonstrate how to connect a digital to analog converter to a microprocessor system.
		2. To demonstrate how a DAC converts digital data to analog data.
		3. To write programs that will convert digital signals to analog signals.

4. To convert a DAC into an analog-to-digital converter (ADC) using a voltage comparator.

5. To write a program that will implement an ADC.

PART III
INDUSTRIAL ROBOTS: ISSUES AND APPLICATIONS

This portion of the curriculum focuses on the applications of robots. Before robotics technology is adopted to perform a specific task, the following issues should be addressed:

1. The job that the robot will be expected to undertake.

2. The characteristics that the robot must have to perform the task.

3. The type of environment in which the robot will operate.

4. The economic and social costs and beneifts associated with the introduction of the robot.

UNIT ONE: IMPLEMENTING A ROBOT

I. Objectives.

Upon mastery of the material presented in this section, the student will have developed the skills necessary to:

1. Develop a model for use in the robot implementation decision-making process.

2. Discuss the types of functions that industrial robots can currently perform.

3. Discuss the purpose for using robots in manufacturing operations.

4. Discuss the adaptations necessary to facilitate robot implementation.

5. Discuss the economics of robotics technology.

II. Content.

1. Candidate application.
    - A. A model for determining the feasibility of robot installation
        - i. Characteristics of successful robot applications.
        - ii. Functions robots can currently perform.
            - a. Pure displacement.
            - b. Displacement and processing.
            - c. Displacement and inspection.
    - B. Analysis of the workplace.
        - i. Dimensions required for robot movements.
        - ii. Robot load handling capacity.
        - iii. Accuracy in positioning manipulator.
        - iv. Speed.
        - v. Supplying materials to the robot.
        - vi. Layout of work space.
        - vii. Type of sensing systems.
        - viii. Environment.
        - ix. Operator training.
        - x. Safety.
    - C. Robot selection.
        - i. Type of grippers.
        - ii. Degrees of freedom.
        - iii. Type of control.
        - iv. Types of auxiliary devices needed to feed the robot.
        - v. Manufacturers of robots and characteristics of the robots.
    - D. Management.
        - i. Effect on the worker.
            - a. Displacement.
            - b. Robot operator characteristics.
            - c. Support personnel.
            - d. Re-training.
        - ii. Effect on the organizational structure.
            - a. Employee job descriptions and pay reclassification.
            - b. Examination of coordination procedures between different departments.
            - c. Training and re-training activities.
            - d. Evaluation of safety proedures.
            - e. New organizational units for evaluating new technologies and future applications, and to facilitate change.
        - iii. Changes in management practices.
            - a. Factors to be considered when introducing robotics technology.
            - b. Processes by which change is facilitated.

2. Economics of robotics technology.
    - A. Job categories that may be affected by robots.

B. Economic justification.
  i. Costs.
    a. Purchase price.
    b. Reorganization of the work place.
    c. Engineering costs.
    d. Learning curve expenses.
    e. Training.
    f. Maintenance.
    g. Installation/start-up costs.
    h. Power costs.
  ii. Potential savings.
    a. Projected increases in quantity of goods produced.
    b. Projected increases in production efficiency.
    c. Reduced manpower requirements.
    d. Improved quality of goods.
    e. Investment credits.
    f. Reduced wastes.
    g. Energy savings.
C. Economic analysis for a proposed robot installation.
  i. Purpose of the analysis.
  ii. Factors for consideration in cash flow projections.
    a. Recurring costs.
  iii. Computation of per-unit costs for proposed robot installation.

3. Social aspects of robot applications.
A. Basic consideratiuons for implementing robots.
  i. Effect on the company's viability.
  ii. Effect on the work force.
B. Factors affecting worker acceptance of robots.
  i. Job security.
  ii. Job enrichment.
  iii. Union-management relations.
  iv. Involvement of workers in robot installations.
  v. Management concern for employee welfare.
  vi. Worker training for coping with new technology.
  vii. Public relations.
C. Union relations and concerns.
  i. Labor retrenchment.
  ii. Pay schedules.
  iii. Robots and standards for human operators.

III. Laboratory Experiments.

The type and variety of exercises for this unit depends upon the type of equipment available to the students. Since the cost of purchasing and maintaining industrial robots will be prohibitive for most school systems, it is assumed that one of the training robot systems listed under the equipment section of this curriculum will be used.

The experiments should be designed to represent the actual work environment as closely as possible. The following suggested experiments are representative of the type of activities appropriate for the secondary school environment.

Objectives	Experiment Title	Purpose
All.	Choosing a robot.	Given a case study of an industrial organization: 1. To identify an application for industrial robots. 2. To develop a plan for implementing a robot in the work place. 3. To illustrate the application of an industrial robot to an appropriate process, using the training robot. 4. To justify introducing a robot in terms of economic and social impacts.

STUDENT EVALUATION

The measurement of student progress in acquiring the knowledge and skills characteristic of an electronics technician should be accomplished through a systematic, continuous program of evaluation. It is recommended that the system used to measure student progress include the following measures:

1. Laboratory reports written by the student, used to assess the student's ability to:
    - A. Adapt theory to practice.
    - B. Express technical information in written form.

2. Practical examinations which include theoretical problems or problems which require verification of theory, requiring that the student design, construct, and evaluate the proposed solutions to the problem.

3. Standardized theory examinations.

APPENDIX A

EMPLOYMENT PRACTICES IN THE ROBOTICS INDUSTRY
TELEPHONE SURVEY

A telephone survey of slected industrial robot manufacturers was conducted to assess the educational and skill levels acceptable for entry level technicians. The following questions formed the basis of interviews conducted with industry representatives:

1. Does your company have a position entitled, "robotics technician"?

2. If not, what title do you assign to technicians responsible for repair, maintenance and assembly of the robots?

3. What type of training do you require your entry-level technicians to possess?

4. What is the minimum experience required for the position?

5. Given the following background, what entry-level positions would a secondary school graduate be qualified to fill?
    A. Electronics, including:
        i. Digital theory, applications, and design.
        ii. Programmable controllers, both software and hardware.
    B. Electromechanics, including:
        i. Basic electromechanics.
        ii. Servo valves and sensors.
        iii. Electrical controls and automation circuits.
        iv. Electromechanical servicing.
    C. Fluid power, including:
        i. Applied hydraulics and pneumatics.
        ii. Hydraulic and pneumatic circuit analysis.
    D. Certification by theoretical and practical examination developed by independent professional organizations.
    E. Robots and automated manufacturing.

6. Will you accept a course in robotics in lieu of experience?

7. Would you consider CWE appropriate experience?

The survey results are presented below for each firm consulted. The names and phone numbers of the representatives interviewed are provided where possible. Also included are the number of robots which have been installed by the vendor, if the information was available.

Automatix, 26 robots.
217 Middlesex Turnpike
Burlington, MA

Charlie Berger
(617) 667-7900

1. No.
2. Electronic/Mechanical Technician.
3. As specified in question #5.
4. None specified.
5. Electronics/Mechanical Technician.
6. Yes.
7. Yes.

ASEA, 1500 robots.
4 King St.
White Plains, NY

Bob Cross
(914) 428-6000

1. No.
2. Electronic/Mechanical Technician.
3. ASEE,ASME.
4. 3 years digital and microprocessor experience.
5. Electrical assembly, mechanical assembly. Must prove competency.
6. No, but it would be a plus.
7. NA

Advanced Robotics Corp
Newark Industrial Park, Bldg. 8
Rt. 79
Hebron, OH 43025

Art Belinger
(614) 870-778

1. No.
2. Electronics Technician.
3. ASEE.
4. 2 years experience in digital electronics and microprocessors.
5. Electronics assembly.
6. A plus.
7. NA.

Amarod, 2 robots
110 Oser Ave.
Hauppauge, NY

1. No.
2. Electronics Technician.
3. ASEE.
4. 3 years microprocessor experience.
5. Electrical technician, but must prove competency.
6. A plus.
7. Yes.

Cincinnati Milacron, 1000+ robots.
Industrial Robot Division
Mason-Morrow Rd.
Lebanon, OH

1. No.
2. Field service technician.
3. ASEE,ASME.
4. ASEE.
5. Field service or in-house technician.
6. A plus.
7. A plus. Would successfully compete.

Copperweld Robotics, 750 robots.
1401 E. 14 Mile Rd.
Troy, MI

Mr. Harris, personnel manager
(313) 585-5090

1. Yes. (Electronic/Electrical/Mechanical Technician).
2. NA.
3. ASEE,ASME.
4. 3 to 5 years experience for #1; 0-3 years for mechanical technician.
5. Mechanical technician.
6. Yes.
7. Yes. Would consider a secondary school student with outlined training and experience.

Cybotech, 600 robots.
P.O. Box 88514
Indianappolis, IN 46208

Mr. Dunlap
(317) 298-5181

1. Yes.
2. NA.
3. ASEE,ASME.
4. 3 to 5 years experience, especially in programmable controllers, digital theory, and design work.
5. Electronics technician.
6. Yes.
7. Yes. The outlined program would make students very competitive for entry-level service positions that would lead to position of service engineer.

General Electric, 1000 robots
Florida, new location

Lynn Barnes
(305) 889-1200

1. No.
2. Mechanical Technician, Electromechanical Technician.
3. ASEE,ASME,ASEET,AS Manufacturing Engineer.
4. Depends on position. Will accept no experience.
5. Yes.
6. A plus.
7. Yes.

ISI, 1000+ robots
31915 Groesbeck Hwy.
Fraser, MI

Phil Nellach
(313) 294-9500

1. No.
2. Service Technician.
3. General Technician.
4. Helpful. No experience necessary; will train in-house.
5. Yes.
6. Yes.
7. Yes.

Pick-O-Matic, 10,000 robots
3750 Commerce Dr.
Sterling Heights, MI

Horace Ludwig
(313) 939-9320

CAM operated equipment. Will hire general education students.

Unimation, 4000 robots
Shelter Rock LA.
Danbury, CT 06810

Randy Fescue
(203) 796-1263

1. No.
2. Electronics technician.
3. ASEE,ASME. Strong in-house training program.
4. 0-3 years.
5. Test Technician.
6. Yes.
7. Yes.

DeVilbiss Co., 900 robots James Kaiser
300 Phillips Ave. (419) 470-2169
P.O. Box 913
Toledo, OH 43692

1. Yes.
2. NA.
3. ASEE,ASME.
4. 3 years experience.
5. Entry level service positions leading to service engineer.
6. Yes.
7. Yes.

NA = No answer or not applicable.

APPENDIX B

EMPLOYMENT IN THE ROBOTICS INDUSTRY: SAMPLE JOB DESCRIPTIONS AND REQUIREMENTS

The following job descriptions are for two entry-level positions in a large robot manufacturing firm.

Electronic Technician

I. Job Summary.

Test, calibrate and repair circuit boards and sub-asseblies. Trouble shoot and debug complex digital, analog, and relay switching, logic circuitry at board and system level.

II. Duties and Responsibilities.

1. Adhere to established methods, routing and test procedures for the testing, calibration, and repairing of circuit boards and sub-asseblies.

2. Maintain failure logs for purpose of feeding back generic, vendor, and in-house quality problems.

3. Train and diret others, as instructed, including assemblers and helpers.

4. Maintain and organize necessary paperwork to operate efficiently.

5. Assist group leader and work with minimum supervision and direction.

6. Perform responsibilities in such a manner that reflects good judgment and meets the department's high standards of quality workmanship and productivity.

7. Performs additional duties and assignments as may be required that are within the scope of the basic function of this position.

III. Job Specifications.

1. Must have proficient soldering and wiring abilities.

2. Must have a thorough knowledge of circuitry used in electronic package of assemblies under test.

3. Must be familiar with use of oscilloscope and other basic test equipment.

4. Must have ability to work to schematic and logic diagrams.

IV. Minimum Requirements.

1. ASEE or equivalent education background and experience.

2. Two years experience with digital electronics in production environment and definite ability to systematically reduce problems encountered in performing basic job function.

Electro/Mechanical Quality Control Technician

I. Job Summary.

Inspect and audit all end items for completeness, compliance to latest change levels, and overall workmanship just prior to release for shipment.

II. Duties and Responsibilities.

1. Inspect finished products to engineering specifications, establish standards, workmanship, and appearance.

2. Control the quality of the product as it is being manufactured, with aim beng to prevent rather than detect defective or off-standard work.

3. Report to supervisor if operators don't conform to quality standards.

4. Harmonious relationship with all related groups to achieve improved quality, production goals, and economy of product.

5. Generate and recommend changes that will improve the design process or quality of the product.

6. Generate and update procedures for final test and in-process inspection of the products.

III. Job Specifications.

1. Try to work within the time frames and schedules set by Production Control, but realizing the #1 priority is a quality product.

2. Strong background in electro/mechanical technology, including manufacturing practices, quality control methods, ability to interface with people and sell goals of quality assurance and total quality control.

IV. Minimum Requirements.

Two year technical school graduate, mechanical/electrical or manufacturing engineering technology, or equivalent experience. Background in quality control and inspection.

APPENDIX C

MANUFACTURERS OF INDUSTRICAL ROBOTS

Advanced Robotics Corporation
Route 79, Newark Industrial Park,
Bldg. 8
Hebron, OH 43025

Anorad
110 Oser Avenue
Hauppauge, NY 11787

Armax Robotics, Inc.
38700 Grand River Avenue
Farmington Hills, MI 48018

ASEA, Inc.
4 New King Street
White Planes, NY 10604

Automation Corporation
23996 Freeway Park Drive
Farmington Hills, MI 48024

Automatix, Inc.
217 Middlesex Turnpike
Burlington, MA 01803

Barrington Automation, Inc.
1002 South Road
Fox River Grove, IL 60021

Bendix Robotics Division
21238 Bridge Street
Southfield, MI 48034

Binks Manufacturing Company
9201 West Belmont Avenue
Franklin Park, IL 60131

CAMCO
Commerical Cam Division
Emerson Electric Co.
1444 S. Wolf Road
Wheeling, IL 60090

Cincinnati Milacron
Industrial Robot Division
Mason-Morrow Road
Lebanon, OH 45036

Control Automation, Inc.
P.O. Box 2304
Princeton, NJ 08540

Copperweld Robotics
1401 East Fourteen Mile Road
Troy, MI 48048

Cybotech
P.O. Box 88514
Indianapolis, IN 46208

The DeVilbiss Company
300 Phillips Avenue
P.O. Box 913
Toledo, OH 43692

Gametics Systems
Gametics, Inc.
15645 Sturgeon
Roseville, MI 48066

GCA Corportion
GCA/PaR Systems
3460 Lexington Ave. North
St. Paul, MN 55112

General Electric Company
Automation Systems
1285 Boston Avenue
Bridgeport, CT 06602

General Electric Company
MAM-MATE Marketing
1000 1st Avenue
King of Prussia, PA 19460

The Hasbach Company
17210 Edwards Road
Cerritos, CA 90710

Hitachi America, Ltd.
6 Pearl Court
Allendale, NJ 07401

Hodges Robotics
International Corporation
3710 N. Grand River Avenue
Lansing, MI 48906

IBM
Advanced Manufacturing Systems
Systems Products Division
P.O. Box 1328
2000 N.W. 51st Street
Boca Raton, FL 33432

International Robomation/Intelligence
6353 EL Camino Real
Carlsbad, CA 92008

I.S.I. Manufacturing, Inc.
31915 Groesbeck Hwy.
Fraser, MI 48026

Lloyd Tool and Manufacturing Co.
2475 E. Judd Road
Burton, MI 48529

MANCA, Inc.
Leitz Building
Rockleigh, NJ 07647

Microbot, Inc.
453-H Ravendale Drive
Mountain View, CA 94043

Midway Machine and Engineering Co.
2324 University Avenue
St. Paul, MN 55114

Mobot Corporation
980 Buenos Avenue
San Diego, CA 92210

Nordson Corporation
555 Jackson Street
P.O. Box 151
Amherst, OH 44001

Pick-O-Matic systems
Division of Fraser Automation
3750 Commerce Drive
Sterling Heights, MI 48077

Positech Corporation
Rush Lake Road
Laurens, IA 50554

PRAB Conveyors, Inc.
5944 E. Kilgore Road
Kalamazoo, MI 49033

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Robotiks, Inc.
507 Prudential Road
Horsham, PA 19044

Seiko Instruments U.S.A., Inc.
2990 West Lomita Blvd.
Torrance, CA 90505

Shin Meiwa Industry Co., Ltd.
Nichimen Co., Inc.
6 North Michigan Avenue
Chicago, IL 60602

Sigma Sales, Inc.
6505 Serrano Avenue
Anaheim Hills, CA 92807

Sterling-Detroit Company
261 East Goldengate
Detroit, MI 48203

Systems Control
30 Thirsk Road
Nothallerton
North Yorkshire
England DL61PH

Thermwood Corporation
P.O. Box 436
Dale, IN 47523

Unimation, Inc.
Shelter Rock Lane
Danbury, CT 06810

United States Robots
1000 Conshohocken Road
Conshohocken, PA 19428

Westinghouse Electric Corporation
Industrial Automation Division
400 High Tower Office Building
400 Media Drive
Pittsburg, PA 15205

X-CEL Controls, Inc.
1600 West 6th Street
Mishawaka, IN 46544

Yaskawa Electric America, Inc.
16722 Hale Avenue
Irvine, CA 92714

APPENDIX D

RECOMMENDED EQUIPMENT

A well equipped laboratory station that will accomodate two students should contain the following instruments, tools, and electrical components:

1. Instruments
    - A. Digital volt, ohm, milliampmeter
    - B. Analoge volt, ohm, milliampmeter
    - C. Function generator
    - D. DC power supplies +/- 0-20 volt (variable)
    - E. High Impedance milli-voltmeter
    - F. General purpose dual trace oscilloscope
    - G. Curve tracer

2. Tools:
    - A. Solderless breadboard, plug-in type preferred
    - B. Needle nose pliers
    - C. Side cutting pliers
    - D. Soldering iron kit
    - E. Alignment tool
    - F. Assorted screwdrivers

3. General supplies:
    - A. Solder (.04" dia, rosin core)
    - B. 20-22 gauge solid core hook-up wire (assorted colors)
    - C. Coaxial cable
    - D. Test lead wire
    - E. Alligator clips and insulators
    - F. Banana plugs

4. Electronic Components:

The specific electronic components needed to support this curriculum are dependent upon the laboratory experiments chosen to illustrate electrical theory. Quantities of the following components are suggested as a guide to equipping each lab station.

A. Resistors

90 1/4 W +/- 5% resistors ranging in value
from 1 ohm to 1 meg ohm
5 assorted high wattage resistors
10 assorted 1/4 W 1% resistors

B. Potentiometers

1 1W 0-1K ohm
1 1W 0-10K ohm
1 1W 0-100K ohm

C. Capacitors (fixed)
Capacitor ratings to be at least 25 volts. 20 assorted capacitors in the range of .001 microfara
to 10 microfarads.

D. Inductors
5 coils in the range of 50 to 750 milliheneries with a Q of 10 or larger in the frequency range of 1 kHz to 20 kHz.

E. Transformers
1 10k ohm to 1740 ohm audio drive transformer
1 117-120v/12.6v-60Hz filament transformer

F. Transistors
An assortment of NPN, PNP, FETs, SCRs, diodes, and vacuun tubes as called for by experiments

G. Integrated Circuits
An assortment of TTL, CMOS and linear ICs as called for by the experiments.

5. Educational Robot Systems

A list of educational robots systems and their manufacturers follows.

EQUIPMENT SOURCES

Laboratory and Demonstration Equipment

1. General Laboratory Equipment

Heath Co.
Benton Harbor, MI 49022

Tektronix, Inc.
P.O. Box 1700
Beaverton, Oregon 97075

B & K Precision
Dynascan Corp.
64560 W. Cortland St.
Chicago, IL 60635

Simpson Electric Co.
853 Dundee Ave.
Elgin, IL 60120

BEC Inc. (used equipment)
2709 n. Broad St.
Philadelphia, PA 19132
(800) 523-3085

E & L Instruments
70 Fulton Terrace
New Haven, CT 06512
(203) 468-1151

2. Educational Robot Systems and There Manufactures

Rhino XR2, Rhino Scorpion
Rhino Robots Inc.
3402 N. Mattis
P.O. Box 4010
Champaign, IL 61820
(217) 352-8485

Microbot Teachmover, Microbot Minimover
453-H Ravendale Drive
Mountain View, CA 94043
(703) 455-5088

Heath/Zenith Hero-1
395 W. Main St. (Rt 44)
Avon Conn.
(203) 678-0323

Feedback
602 Springfield Ave.
Berkeley Heights, NJ
(201) 464-5181

Amatrol
P.O. Box 2097
Clarksville, IN 47131
(812) 288-8285

Brat 801
Amptronics
401 N. Salem Av.
Arlington Heights, IL 60005
(312) 870-0883

Androbot Inc.
P.O. Box 9-214
San Jose, CA 95103
(408) 262-4914

Hand Tools and Electronic Components

1. Electronics parts dealers

Digi-Key Corporation
Highway 32 South, P.O. Box 677
Thief River Falls, MN 56701
(800) 345-5144

Mouser Electronics
11433 Woodside Ave.
Santce, CA 92071

Poly Paks
P.O. Box 942R
Lynn, MA 01940
(617) 245-3289

Radio Shack (local directory)

Solid State Sales
P.O. Box 74D
Somerville, MA 02143
(617) 547-4005

Priority One Electronics
9161 Deering Ave.
Chatsworth, CA 91311
(800) 423-5922

Audio-Visual Aids

Bell Systems Telephone Business Offices

Tektronix Inc. Film Library
P.O. Box 1700
Beaverton, Oregon 97075

Prentice-Hall Media
150 White Plains Road
Terrytown, NY 10591

Heath Co.
Benton Harbor, MI 49022

Triplett Corp.
One Triplett Drive
Bluffton, OH 45806

APPENDIX E

TEXTBOOKS AND REFERENCE MATERIALS

Basic Electronics, Circuit Theory, and Integrated Circuits

Boylestad, Robert and Louis Nashelsky [1978]. *Electronic Devices and Circuit Theory*. Englewood Cliffs, New Jersey 07632: Prentice-Hall, Inc.

Floyde, Thomas L. [1981]. *Principles of Electronic Circuits*. Columbus, Ohio 43216: Charles E. Merrill Publishing Co.

Heath Co. [1978]. *DC Electronics*. Benton Harbor, MI 49022.

Heath Co. [1978]. *AC Electronics*. Benton Harbor, MI 49022.

Heath Co. [1979]. *Electronic Test Equipment* Benton Harbor, MI 49022.

Heath Co. [1978]. *Semiconductor Devices*. Benton Harbor, MI 49022.

Heath Co. [1978]. *Electronic Circuits*. Benton Harbor, MI 49022.

Heath CO. [1981]. *Operational Amplifiers*. Benton Harbor, MI 49022.

Heath Co. [1981]. *Active Filters*. Benton Harbor, MI 49022.

Heath CO. [1981]. *Phase Locked Loops*. Benton Harbor, MI 49022.

Heath Co. [1981]. *IC Timers*. Benton Harbor, MI 49022.

Heath CO. [1981]. *Optoelectronics*. Benton Harbor, MI 49022.

Heath Co. [1981]. *Linear Circuits*. Benton Harbor. MI 49022.

Heath Co. [1981]. *TTL/CMOS*. Benton Harbor, MI 49022.

Herrick, Clyde [1973]. *Survey of Electronics*. New York: The MacMillian Co.

Jackson, Herbert [1976]. *Introduction to Electronic Circuits*. Englewood Cliffs, New Jersy 07632: Prentice-Hall.

Mandel, Matthew [1977]. *Solid State Circuit Designers Handbook*. Reston, Va 22090: Reston Publishing Co.

Digital Theory and Computer Architecture

Artwick, Bruce A. [1980]. Microcomputer Interfacing. Englewood Cliffs, New Jersey 07632: Prentice-Hall.

Bartee, Thomas C. [1976]. Digital Computer Fundamentals. New York: McGraw-Hill Book Co.

Deen, Bill, Kenneth Mucrow, Anthony Zeppa [1977]. Digital Computer Circuits and Concepts. Reston VA 22090: Reston Publishing Co.

Heath Co. [1978]. Digital Electronics. Benton Harbor, MI 49022.

Heath Co. [1978]. Microprocessors. Benton Harbor, MI 49022

Heath Co. [1983]. Advanced Microprocessors. Benton Harbor, MI 49022

Hilburn, John L. and Paul M. Julich [1976]. Microcomputers/microprocessors. Englewood Cliffs, New Jersey 07632: Prentice-Hall.

Kingman, Edwin E. [1977]. Microprocessor Systems Design. Englewood cliffs, New Jersey 07632: Prentice-Hall.

Osborne, Adam [1977]. An Introduction to Microprocessors
Volume 0, The Beginners Book
Volume I, Basic Concepts
Volume II, Some Real Products
Berkeley, California 94720: Adam Osborne and Associates, Inc.

Rony, Peter R., David G. Larsen, and Jonathan A. Titus [1976]. The Bug Books I, II, III, IV, V, VI. 61 First Street, Derby Conn 01418: E and L Instruments Inc.

Rutkowski, George B. and Jerome E. Oleksy [1978]. Fundamentals of Digital Electronics: A Laboratory Text. Englewood Clifs, New Jersey 07632: Prentice-Hall.

Sloan, M.E. [1976]. Computer Hardware and Organization. Chicago, Ill: Science Research Associates, Inc.

Robotics

Ayers, Peter R. and Steven M. Miller [1983]. Robotics: Applications and Social Implications. Cambridge Mass: Ballinger Publishing Co.

Computerized Manufacturing: Automation, Employment, and the Workplace. Superintendent of Documents, U.S. GPO, Washington, D.C. 20402, April, 1984.

Heath, Larry [1984]. *Fundamentals of Robotics: Theory and Applications*. Reston VA 22090: Reston Publishing Co.

Heath Co. [1983]. *Robotics and Industrial Electronics*. Benton Harbor, MI 49022.

Heath Co. [1984]. *Robot Applications*. Benton Harbor, MI 49022

International Robotics Industrial Directory, 4th ed. Technical Data Base Corporation, P.O. Box 720; Conroe, TX 77305.

Osborne, David M. [1984]. *Robotics: An Introduction to Basic Concepts and Applications*. Detroit MI 48212: Midwest Sci-Tec Publishers Inc.

Troubleshooting

Cameron, Derek [1976]. *Advanced Electronic Troubleshooting*. Reston VA 22090: Reston Publishing Co.

Gilmore, Charles [1976]. *Understanding and Using Modern Electronic Servicing Test Equipment*. Blue Ridge Summit, PA: TAB Books.

Robinson, Vestor [1977] *Manual of Solid State Circuit Design and Troubleshooting*. Reston VA 22090: Reston Publishing Co.

Magazines and Journals

Byte, Byte Inc., Division of McGraw-Hill, Peterborough NH.

Creative Computing, AHL Computing, Morristown, NJ.

Popular Electronics, Ziff-Davis, New York, NY.

Radio Electronics, Gernsback Publications, New York, NY.

Robotics Age, Robotics Age Inc., Strand Building, 174 Concord St., Peterborough, NH 03458.

Robotics Today, Society of Manufacturing Engineers, One SME Drive, P.O. Box 930, Dearborn MI 48121.

Robotics Tomorrow, Robotic Society of America, RSA 20C California Ave., Suite 215, Palo Alto, California 94306.

Robotics World, Robotics World, Communications Channels Inc., 6255 Barfield Road, Atlanta, Georgia 30328.

Sensors, North American Technology Inc., 174 Concord St., Peterborough, NH 03458.

Publishers of Textbooks, Lab Manuals, Workbooks, and Product Information

Charles E. Merrill Publishing Co.
Columbus, OH 43216

Heath Co.
Benton Harbor, MI 49022

Tektronix Inc.
P.O. Box 1700
Beaverton, Oregon 97075

Delmar Publishers
2 Computer Drive West
Albany, NY 12205

Van Norstand Reinhold Co.
135 West 50 St.
New York, NY 10020

McGraw-Hill
1221 Avenue of the Americas
New York, NY 10020

Prentice-Hall
Englewood Cliffs, New Jersey

Reston Publishing Co.
Reston, VA 22090

General Instruments
3400 Hillview Ave
Palto Alto, CA 94304

Motorola Semiconductor Products, Inc.
Box 20912
Phoenix, AZ 85036

RCA
Box 3200, Route 202
Somerville, NJ 08876

Signetics Corporation
811 East Augeus Ave.
Box 409
Sunnyvale, CA 94086

Texas Instruments, Inc.
Box 5012
Dallas, TX 75222

Fairchild Semiconductor
464 Ellis Street
Mountain View, CA 94042

Intel Corporation
3065 Bowers Avenue
Santa Clara, CA 95014

ITT Semiconductors
Madistone Road
Footscary Sidcup
Kent, England

National Semiconductor
2900 Semiconductor Drive
Santa Clara, CA 95050

Western Digital
3128 Red Hill AV.
Newport Beach, CA 92663

Zilog Microcomputers
10460 Bubb Rd.
Cupertino, CA 95014

REFERENCES

Ayres, Robert U., and Steven M. Miller [1983]. *Robotics: Applications and Social Implications*. Cambridge, MA: Ballinger Publishing Co.

Ashley, William, Robert Abram, Edward Konopka, and Lloyd R. Carrico [1983]. *Preparing for High Technology: Robotics Programs*. Ohio State University: The National Center for Research in Vocational Education.

1983 Robotics Industry Directory [1983]. Conroe, TX: Technical DataBase Corp.

State of Connecticut Board of Education [1981]. *A Guide to Curriculum Development in Vocational Education*.

A Survey of Industrial Robots [1983], 2nd ed. Dallas, TX: Leading Edge Publishing Co.

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